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FLIGHT TESTS FOR THE DIGITAL INTEGRATED
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COMPLETE SET OF FLIGHT DATA (NASA) 330 p
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IMPLEMENTATION AND FLIGHT TESTS FOR THE DIGITAL INTEGRATED
AUTOMATIC LANDING SYSTEM (DIALS)

Part 2 - Complete Set of Flight Test Data

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IMPLEMENTATION AND FLIGHT TESTS

FOREWORD

The motivation for the Digital Automatic Landing System (DIALS) research and the program supporting the effort are covered in the introduction of part one of this report. Part one presents the implementation details and selected flight test results.

This second part of the report presents the complete set of flight test results for the last five DIALS test flights (those free of major software errors). This report will define the variables which are plotted for each data run and flight test. A general description of each of the flight tests will be given along with specific differences from run to run and flight test to flight test. Data plots for each run of each flight test are included.

DESCRIPTION OF PLOTTED VARIABLES

Sixty-two (62) variables are plotted for each run for each flight test. The first forty-two (42) variables of the plots were recorded at 40 samples/second and are plotted at 4 samples/second. The last twenty (20) variables were recorded at 20.3451 samples/second and were plotted at 4.069 samples/second. The definition of the plotted variables in the order of occurrence is as follows:

V_a	calibrated airspeed from the central air data computer, knots (the y-axis is centered about desired airspeed)
q	aircraft body-axis pitchrate from a rate gyro, deg/sec; positive for pitch increasing
θ	aircraft pitch attitude from the inertial platform, deg; positive for nose up
$\theta_o + e_{Lx1}$	sum of the trim pitch attitude and the DIALS estimated perturbed pitch attitude, deg.; positive for nose up
a_n	specific force along negative z-body axis from the normal body-mounted accelerometer, ft/sec; positive acceleration upward
a_x	specific force along x-body axis from longitudinal body body-mounted accelerometer, ft/sec; positive acceleration forward
Δh	the altitude deviation from the desired flight path ($\Delta h = -e_{Lx6} U_o$), ft; positive is above path
\dot{h}_{MLS}	estimate of the vertical velocity from the third-order complementary filter, ft/sec; positive altitude increasing
u_{cL1}	DIALS elevator position comand, deg; positive trailing edge down
δ_e	elevator surface position deflection relative to the stabilizer chord plane, deg; positive trailing edge down

u_{CL3} DIALS throttle rate command, deg/sec; positive throttle increase
 δ_{th} the average of the forward left and right throttle positions, deg; positive throttle increase
 δ_{ec} elevator servo position command, deg; positive trailing edge down
 e_{Lx3} DIALS estimate of the inertial angle-of-attack, deg
 $\int \Delta h$ the integral of altitude deviation from the desired altitude trajectory ($-\Delta h = e_{Lx6}$), ft/sec
 u_{CL2} stabilizer rate command, deg/sec; positive trailing edge down
 δ_{stab} the stabilizer surface position relative to the fuselage reference line, deg; positive trailing edge down
 \dot{h}_B barometric vertical velocity, ft/sec; positive altitude increasing
 e_{Lx2} DIALS estimate of the inertial speed error along the x-stability axis, knots; positive too fast
 $U_o + z_{L2}$ sum of trim airspeed and desired inertial speed from U_o along the x-stability axis, knots; positive above trim
 $T_o + e_{Lx7}$ sum of trim thrust and DIALS estimated perturbed thrust from trim, lbs; always positive
EPR average of the left and right engine pressure ratios; always positive
 $\delta_{Th_{EST}}$ DIALS estimate of the throttle position, deg; always positive
 $\delta_{Th_{AFT}}$ the position of the aft servo throttle position, deg; always positive
 ϕ the roll attitude from the inertial platform, deg; positive right wing down
 Δy DIALS estimate of the position deviation from runway centerline, ft; positive to right of centerline
 $\Delta \psi$ yaw attitude deviation from the runway heading obtained from the inertial navigation system, deg; positive nose right of runway
 $\Delta \psi_{est}$ DIALS estimate of the yaw attitude deviation from the runway centerline, deg; positive nose right of runway
 w_5 DIALS estimate of the wind in the direction of the y-body axis, knots; positive in negative y-body axis direction
 z_3 the desired inertial speed computed by DIALS along the y-body axis, knots; positive in direction of y-body axis
 $\Delta \psi_{TK}$ the deviation in ground track angle from the runway heading obtained from the inertial navigation system, deg; positive for track to right of runway centerline

ϕ_{EST} DIALS estimate of the aircraft roll attitude, deg; positive right wing down
 p the aircraft roll rate about the y-body axis, deg/sec; positive nose moving to right
 r the aircraft yaw rate about the z-body axis, deg/sec; positive nose moving to right
 a_y specific force along the y-body axis from the body-mounted accelerometer, ft/sec; positive right for acceleration in the direction of the y-body axis
 u_{c1} DIALS aileron position command, deg; positive right wing down
 u_{c2} DIALS rudder rate command, deg/sec; positive for nose to right
 δ_{ac} aileron servo position command, deg; positive right wing down
 δ_{aA} aileron servo position for the A servo, deg; positive right wing down
 δ_{aB} aileron servo position for the B servo, deg; positive right wing down
 δ_R rudder servo position, deg; positive trailing edge left (negative yaw)
 β aerodynamic sideslip angle, deg; positive for relative wind to right of nose
 y_{INT} the integral of the DIALS estimate of position deviation from runway (Δy), ft/sec
 v_θ DIALS pitch innovation, deg; measurement minus predicted
 b_θ DIALS estimate of the bias on pitch attitude measurement, deg
 v_x DIALS runway x-coordinate innovation, ft; measurement minus predicted
 v_z DIALS runway z-coordinate innovation, ft; measurement minus predicted
 E_L MLS elevation measurement, deg; always positive
 v_h^* DIALS vertical velocity innovation, ft/sec; measurement minus predicted
 b_h^* DIALS estimate of bias on vertical velocity measurement, ft/sec
 v_{a_z} DIALS normal acceleration innovation, ft/sec; measurement minus predicted
 b_{a_z} DIALS estimate of the bias on the normal accelerometer measurement, ft/sec
 x_{MLS} velocity estimate of aircraft along MLS x-coordinate frame from third-order complementary filter, ft/sec; negative in direction of landing
 v_{V_a} DIALS airspeed innovation, ft/sec; measurement minus predicted
 $w_{L4} + w_{L5}$ sum of DIALS estimate of the gust wind and steady wind in the direction of the x-body axis, knots; positive for headwind

v_{ax}	DIALS longitudinal acceleration innovation, ft/sec; measurement minus predicted
b_{ax}	DIALS estimate of the bias on the longitudinal accelerometer measurement, ft/sec
\dot{y}_{MLS}	velocity estimate of the aircraft along the MLS y-coordinate frame from the third-order complementary filter, ft/sec; positive for aircraft approaching runway centerline from left
v_{ϕ}	DIALS roll attitude innovation, deg; measurement minus predicted
v_{ψ}	DIALS yaw attitude innovation, deg; measurement minus predicted
v_{ay}	DIALS lateral acceleration innovation, ft/sec; measurement minus predicted
v_y	DIALS runway y-coordinate innovation, ft; measurement minus predicted
Az	MLS azimuth measurement, deg; positive to left of runway centerline

DESCRIPTION OF DIALS SOFTWARE CHANGES FOR EACH FLIGHT TEST

The general purpose of the flight tests, (figs. 1 through 27) was primarily to gather data for performance evaluation of the DIALS various control modes (glideslope and localizer capture, glideslope and localizer track, decrab, and flare). As the flight tests progressed, changes were made to the DIALS software. These changes included gain changes as a result of nonlinear simulation evaluations being conducted simultaneously with flight tests and coding changes as a result of errors discovered in the flight software during data analysis. Table 1 of part 2 relates the differences in software from a defined baseline condition for each run of the flight tests. The baseline condition is defined as the software equations and gains presented, respectively, in appendix A and appendix B of Part 1 of this report (the software and gains for the last flight test - R364). The software differences and gain changes are described below.

For flight test R353 (conducted on 9-29-81) there are both gain and software code differences from the baseline. The gain on pitch feedback for the elevator command, h_{Lx11} , and the gain on pitchrate feedback for the elevator command, h_{Lx14} , differed from the baseline as noted in table 1. The gains were set to different values during the flight tests to improve the short period damping and to eliminate or reduce a low amplitude high frequency elevator oscillation. On the first run, Run 6 (see fig. 1), h_{Lx11} was set to -3.8 and h_{Lx14} was set to the baseline value of -2.2. On the next run, Run 6R1 (see fig. 2), and for the remainder of the runs for this flight h_{Lx11} was set to the baseline value of -4.5 and h_{Lx14} was set to -2.5. The result of using the larger magnitude gains are larger peak to peak amplitudes of the high frequency elevator oscillations (see δ_e plots of figs. 2 and 3). Another difference from baseline was the values of the flare gain increase factors-- h_{Lxf3} , h_{Lxf4} , h_{Lxf6} . These factors were changed to improve tracking of the desired flare trajectory. The gain factors used for the first run were unacceptable since they caused large amplitude oscillations to occur in the elevator. (See the plotted elevator data, δ_e , near the end of the run.) However, for Runs 6R1 through 7R1, (figs. 2 through 7) these factors were not executed during flare due to a coding error and thus the flare gains were not increased for these runs (the error

was such that the factors were only done for the first flare execution). In other words, the coding error was as if these factors had values of 1 after the first flare execution. Main gear touchdown occurred with the automatic system engaged for all these runs except Run 6R3 but column inputs from the forward flight deck pilot occurred for all runs except the last one (Run 7R1). Two other coding errors were also present for this flight test. One caused an incorrect commanded value of the inertial sideslip, z_3 , when the roll attitude reached the decrab roll limit. This error is evident in the data plot of z_3 for Run 6 of this flight test (note pulse in z_3 near end of the run). The other error was an incorrect value for the glidepath intercept point, x_{GPIP} , used in the glideslope capture criteria. The incorrect value differed from the correct value used in the glideslope capture and track equations by 150 feet and thus, the initiation of the glideslope capture was in error. As a matter of record, the value used in the capture criteria was that defined for a glideslope through the aircraft center-of-gravity whereas the x_{GPIP} value for the capture and track equations was for a glideslope along the bottom of the main landing gear. These values differed by about 150 feet. Another parameter that had values different from baseline was the commanded airspeed reduction factor for flare, ΔV_{FR} , as noted in table 1. Its value was 1.25 for Runs 6 through 6R2, 1.65 for Runs 6R3 and 6R4, and 1.85 for Runs 7 and 7R1. The value was increased to achieve more airspeed reduction in flare so that a sufficient positive pitch attitude would result at touchdown. The result of this increase is difficult to determine for this flight since pilots column inputs occurred on all runs except Run 7R1.

For test flight R355 (conducted on 10-20-81) two of the software errors of R353 stilled remained--the incorrect x_{GPIP} value for the capture criteria and the flare gain increase error. For this flight test, the flare gain increase error did not come into play until the third run (Run 8) since flare was not executed on the first run (Run 7, fig. 8). Run 7 was stopped after it was discovered that the wrong desired glideslope angle had been selected and therefore no longitudinal control laws were executed for the run. For Run 7R1 (fig. 9), where the flare factors were executed, large elevator oscillations occurred and these factors are clearly unacceptable. On subsequent runs these factors were effectively 1 due to the software error. On Run 10 (fig. 12), the feedback gain on pitch to elevator command, h_{Lx11} , differed from that for the baseline. The gain was changed from -4.5 to -5.0 to reduce the low amplitude elevator oscillations (column activity). No conclusion can be drawn as a result of this gain change by comparing the elevator position data plots of runs 9 and 10 (figs. 11 and 12). For run 10 less elevator activity occurs during the glideslope capture but more activity occurs during flare. However, Runs 11 (fig. 12) and 13 (fig. 14), which have $h_{Lx11} = -4.5$ also have more elevator activity during flare than Run 9 (fig. 11). This increased activity during flare was probably due to increased turbulence at the lower altitude.

On flight test R357 (conducted on 11-18-81), all known software errors had been corrected. The differences from baseline for this flight consisted of different values for two of the three flare gain increase factors h_{Lxf_3} and h_{Lxf_6} , and a different value for the feedback gain on pitchrate to elevator command, h_{Lx14} . The flare gain factors were reduced from flight R355 but were still higher than the baseline. The result of using these higher values is difficult to ascertain from the data because only one flare was carried to touchdown (Run 7, fig. 15) due to excessively high crosswinds encountered during the tests. However, the data does show that no increase in elevator activity is apparent during the flare maneuver. Figures 16 through 21 show the data for runs 7R1 through 11.

The software for flight test R361, conducted on December 4, 1981 in mild wind conditions, was the same as the baseline on one of the three runs of this flight and only had one parameter difference for each of the other two runs, Run 7 (fig. 22) and 8 (fig. 23). On Run 7, the pitchrate feedback gain for the elevator command was set to -2.0 compared to the baseline value of -2.2. Comparing the plots of pitchrate, the curves for Runs 8 and 9 (fig. 24) appear to be smoother than that of Run 7 with the lower gain. However, a 4.5 degree glideslope was being tracked on Runs 8 and 9 rather than 3 degree glideslope and the wind conditions along the lower glideslope may have been slightly more turbulent. On Run 9, the commanded airspeed reduction factor during flare was set to 1.85 from the baseline value of 1.65. This increase resulted in a higher pitch attitude for the aircraft at touchdown.

The software for flight test R364, conducted of December 11, 1981 in strong gust conditions and 18 knot crosswinds, was only changed from baseline on two runs. On the second run (Run 5, fig. 26), the body-mounted accelerometer filters were enabled which appeared to have no effect on the system performance. On the last run (Run 6R1, fig. 29), a number of gains, which were relatively small compared to other gains, were set to zero as indicated in table 1 to gather data for comparison with an ongoing nonlinear simulation effort. The purpose of the simulation effort was to develop a simplified version of DIALS that would require less memory and less real-time for code execution while maintaining essentially the same performance. The results show that performance was not affected using the zeroed gains. Both runs, 6 (fig. 27) (with non-zero gains) and 6R1 (with zeroed gains), resulted in complete "hands off" automatic landings with acceptable touchdown parameter values.

One note relative to the flight software is that one other error was discovered in the existing code during the preparation of this report. The error is that the gain of the feedback of the aileron servo position in the lateral innovation equations was a factor of 4 too large due to a scaling error in the fixed-point flight computer. Computer simulations to quantify the effect of this error were not performed.

TABLE 1.- Difference in DIALS Software for Various Flight Tests From
Baseline Plus Desired Glideslope and Initial Track

Flight Test	Run No.	G/S (deg)	$\Delta\psi_{TK}$ (deg) at Loc Cap	Comments/Changes from Baseline
R364	4	3	32	Baseline
	5	4	28	Enable B.M. Accel Filters
	6	4.5	33	Baseline
	7	5	28	Baseline
	6B1	4.5	30	Simplified DIALS $f_{Lx_{i4}} = 0$ for $i = 1,2,3,4,5$ $f_{Lx_{i5}} = 0$ for $i = 1,2,3,4,5$ $f_{Lx_{i8}} = 0$ for $i = 1,3,4,6$ $f_{Lw_{i3}} = 0$ for $i = 1,2,3,4,6,7$ $f_{Lw_{i4}} = 0$ for $i = 2,3,4,5,7$ $f_{Lw_{i5}} = 0$ for $i = 1,2,3,4,5,6,7$ $\psi_{Lw_j} = 0$ for $j = 1,2,3$ $\gamma_{L4_j} = 0$ for $j = 1,2,3$ $\gamma_{Lw_{4j}} = 0$ for $j = 1,3,4,5,6$ $\phi_{L12} = 0, \phi_{L24} = 0$ $\phi_{L4_j} = 0$ for $j = 1,2,3,4$ $\phi_{Li4} = 0$ for $i = 5,6$ $\phi_{Li7} = 0$ for $i = 1,3,4,5,6$ $\phi_{Li8} = 0$ for $i = 1,2,3,4,5,6$ $\phi_{Li9} = 0$ for $i = 2,4,5,6$
R361	7	3	29	$h_{Lx14} = -2.0$
	8	4.5	23	Baseline
	9	4.5	28	$\Delta v_{FR} = 1.85/u_o$
R357	7	3	30	$h_{Lsf_3} = 1.5, h_{Lxf_6} = 1.5$ $h_{Lx14} = -2.0$
	7B1	3	30	Same as Run 7
	8	4.5	20	
	9		26	
	10		38	
	11		49	

TABLE 1.- Concluded

Flight Test	Run No.	G/S (deg)	$\Delta\psi_{TK}$ (deg) at Loc Cap	Comments/Changes from Baseline
R355	7	3	20	Longitudinal not engaged due to G/S selection; see Notes 1 and 2
	7R1	3	20	See Notes 1 and 2
	8	3	30	See Notes 1, 2 and 3
	9	3	40	See Notes 1, 2 and 3
	10	3	50	See Notes 1, 2 and 3; $h_{Lx11} = -5.0$
	11	4.5	20	See Notes 1, 2 and 3
	13	4.5	40	See Notes 1, 2 and 3
R353	6	3	30	$h_{Lx11} = -3.8$, $\Delta v_{FR} = 1.25/u_o$ See Notes 2, 4 and 5 Baseline
	6R1	3	36	$h_{Lx14} = -2.5$, $\Delta v_{FR} = 1.25/u_o$ See Notes 2, 3, 4, 6 Baseline
	6R2	3	27	$h_{Lx14} = -2.5$, $\Delta v_{FR} = 1.25/u_o$ See Notes 2, 3, 4, 6 Baseline
	6R3	3	35	$h_{Lx14} = -2.5$, See Notes 2, 3, 4, 6 Baseline
	6R4	3	29	$h_{Lx14} = -2.5$, See Notes 2, 3, 4, 6 Baseline
	7	4.5	28	$h_{Lx14} = -2.5$, $\Delta v_{FR} = 1.85/u_o$ See Notes 2, 3, 4, 6
	7R1	4.5	29	$h_{Lx14} = -2.5$, $\Delta v_{FR} = 1.85/u_o$ See Notes 2, 3, 4, 6

Note 1: $h_{Lxf_3} = 2.0$, $h_{Lxf_4} = 3.0$, $h_{Lxf_6} = 2.0$.

Note 2: X_{GPIP} value in glideslope capture criteria incorrect.

Note 3: No flare feedback gain increase due to coding error.

Note 4: Error in decrab software logic.

Note 5: $h_{Lxf_3} = 2$, $h_{Lxf_4} = 2.5$, $h_{Lxf_6} = 2.5$.

Note 6: $h_{Lxf_4} = 3$, $h_{Lxf_6} = 2$.

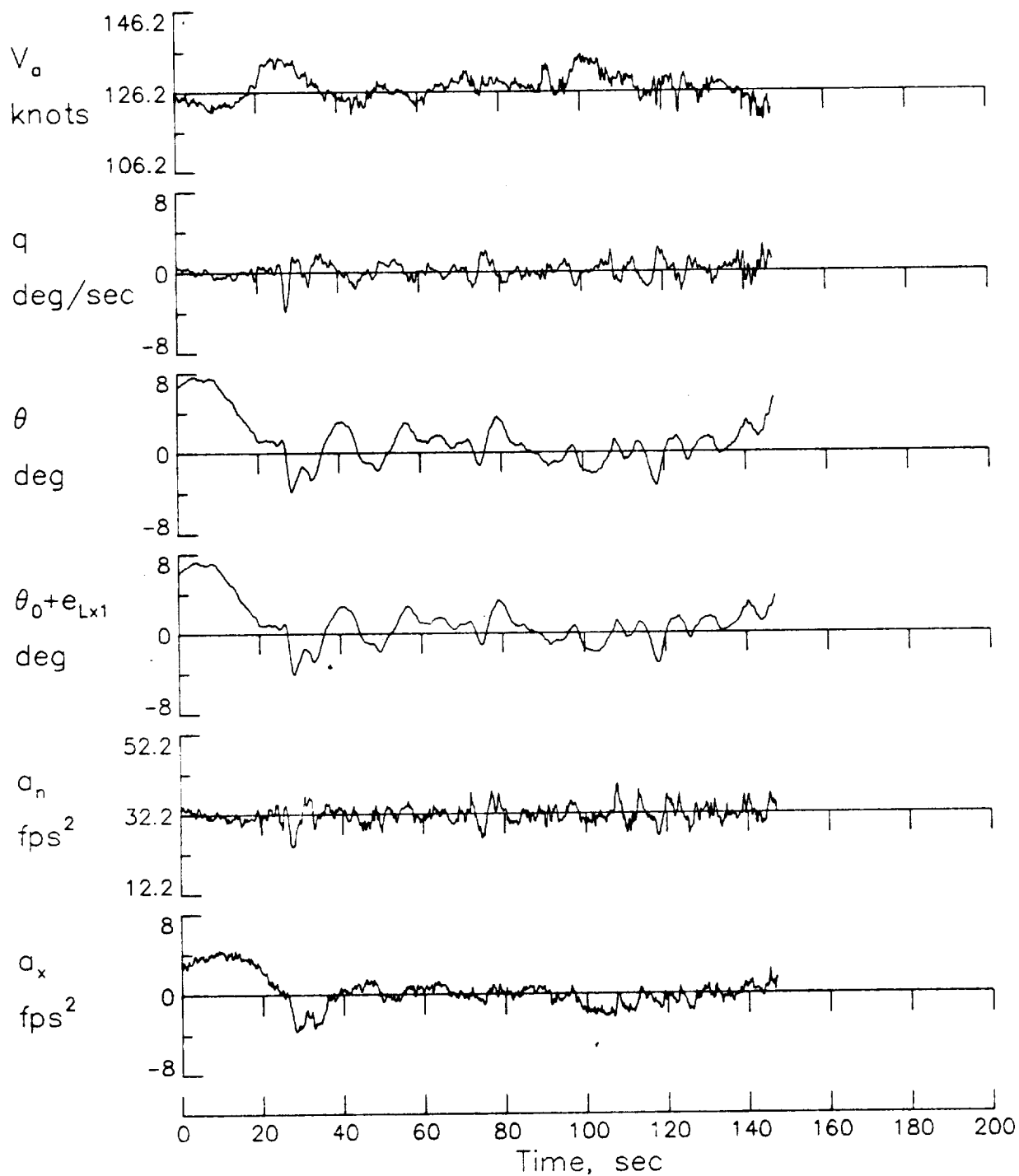


Figure 1. Flight Data for DIALS Flight Test
R353, Run 6

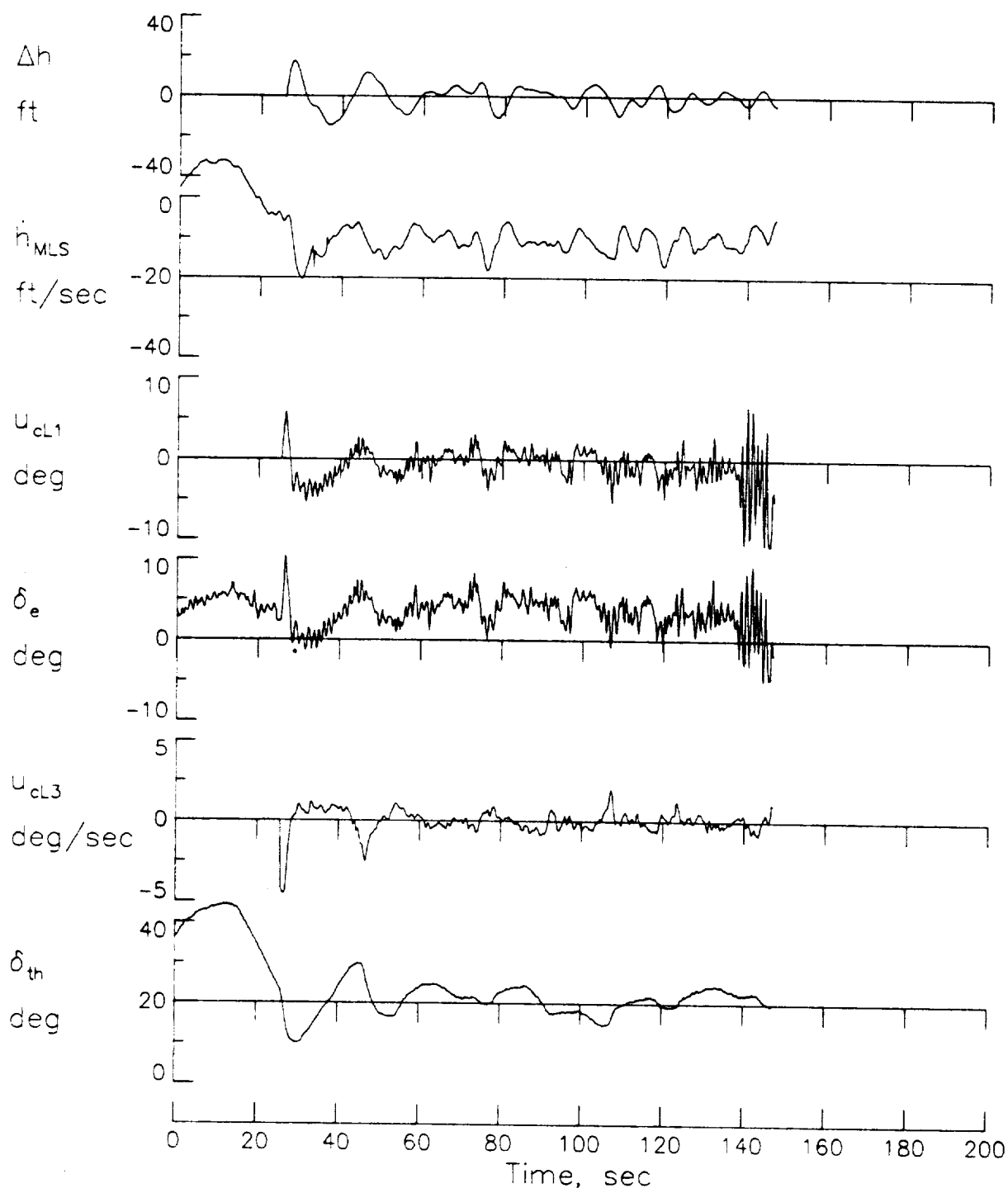


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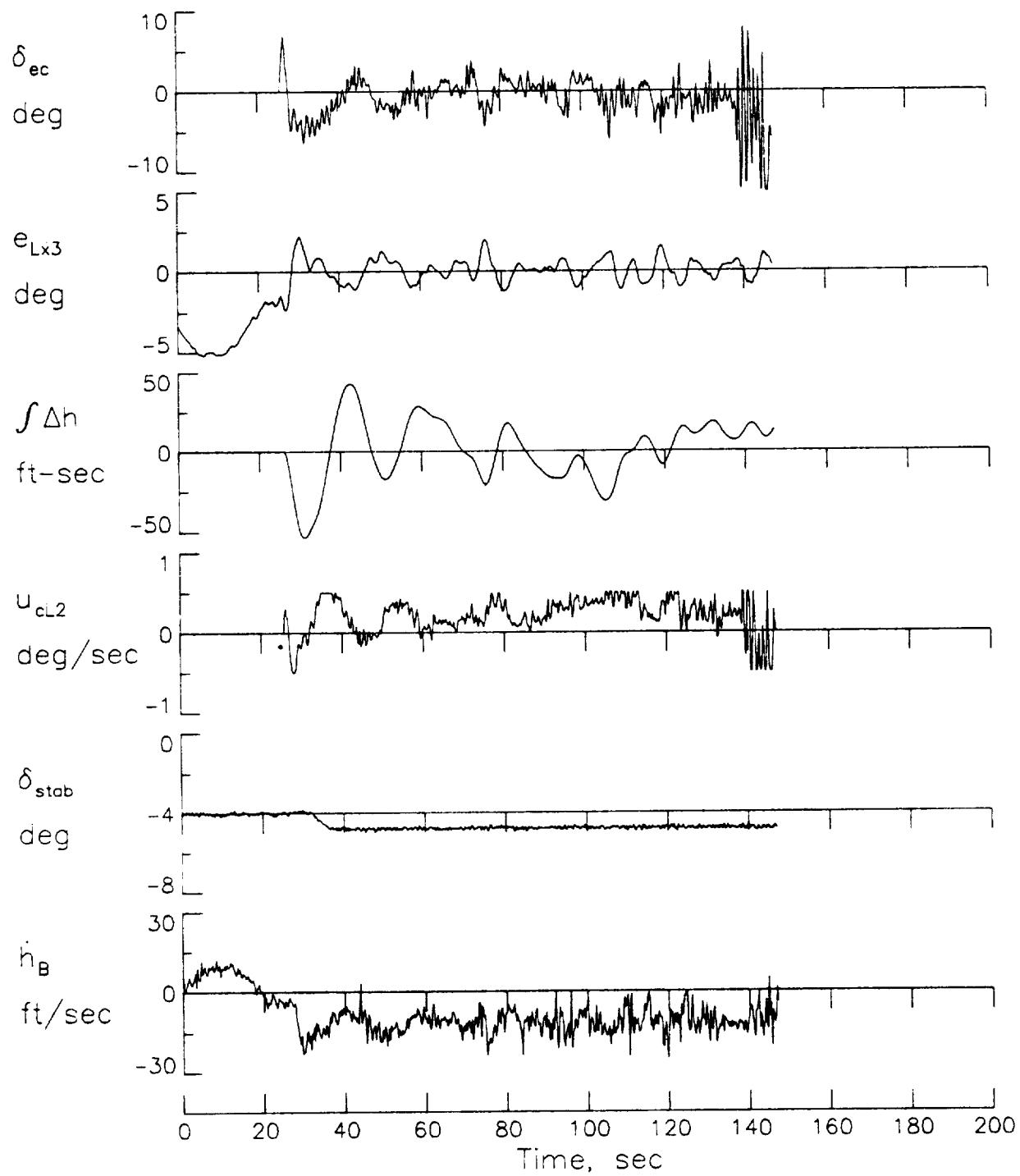


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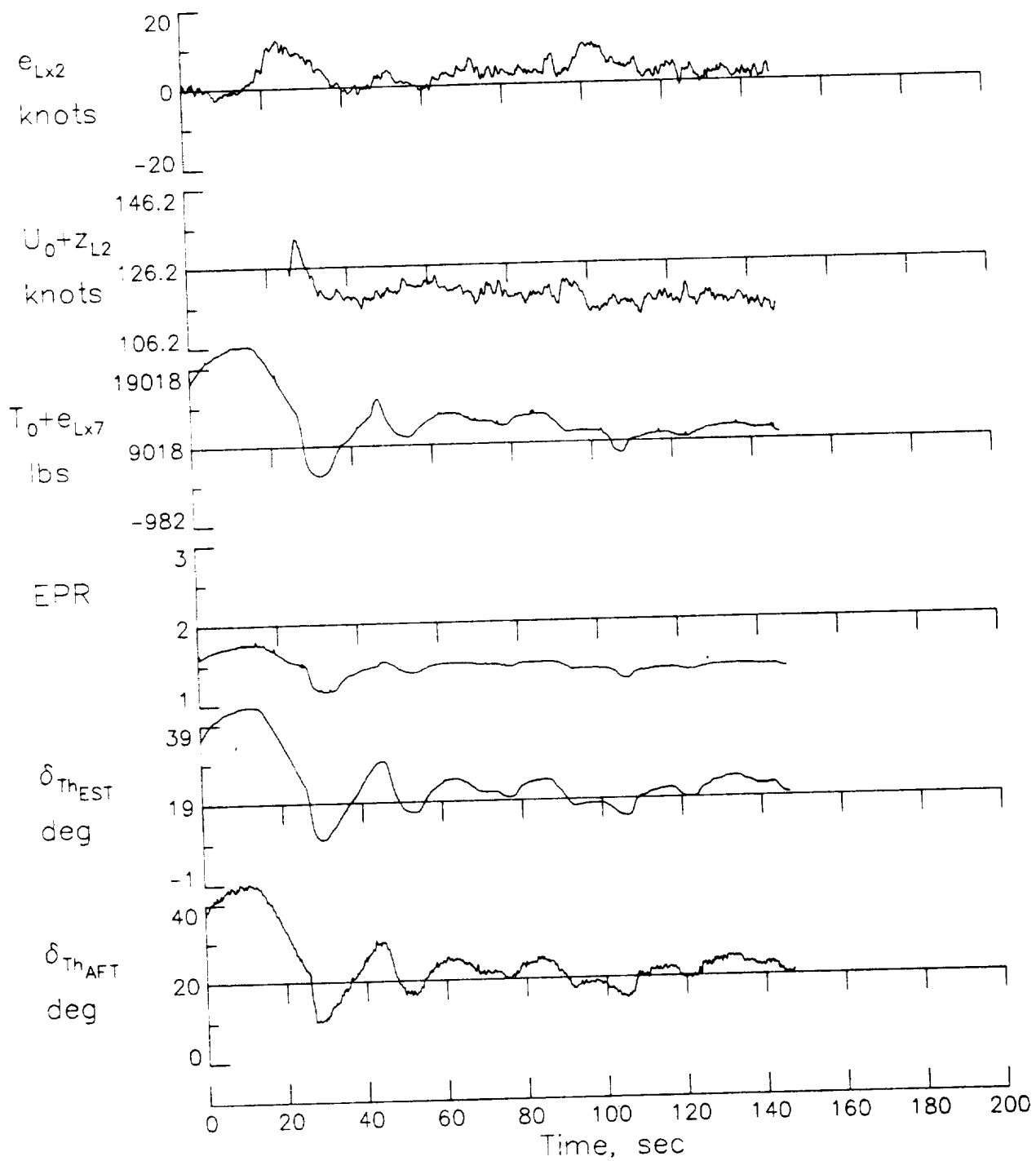


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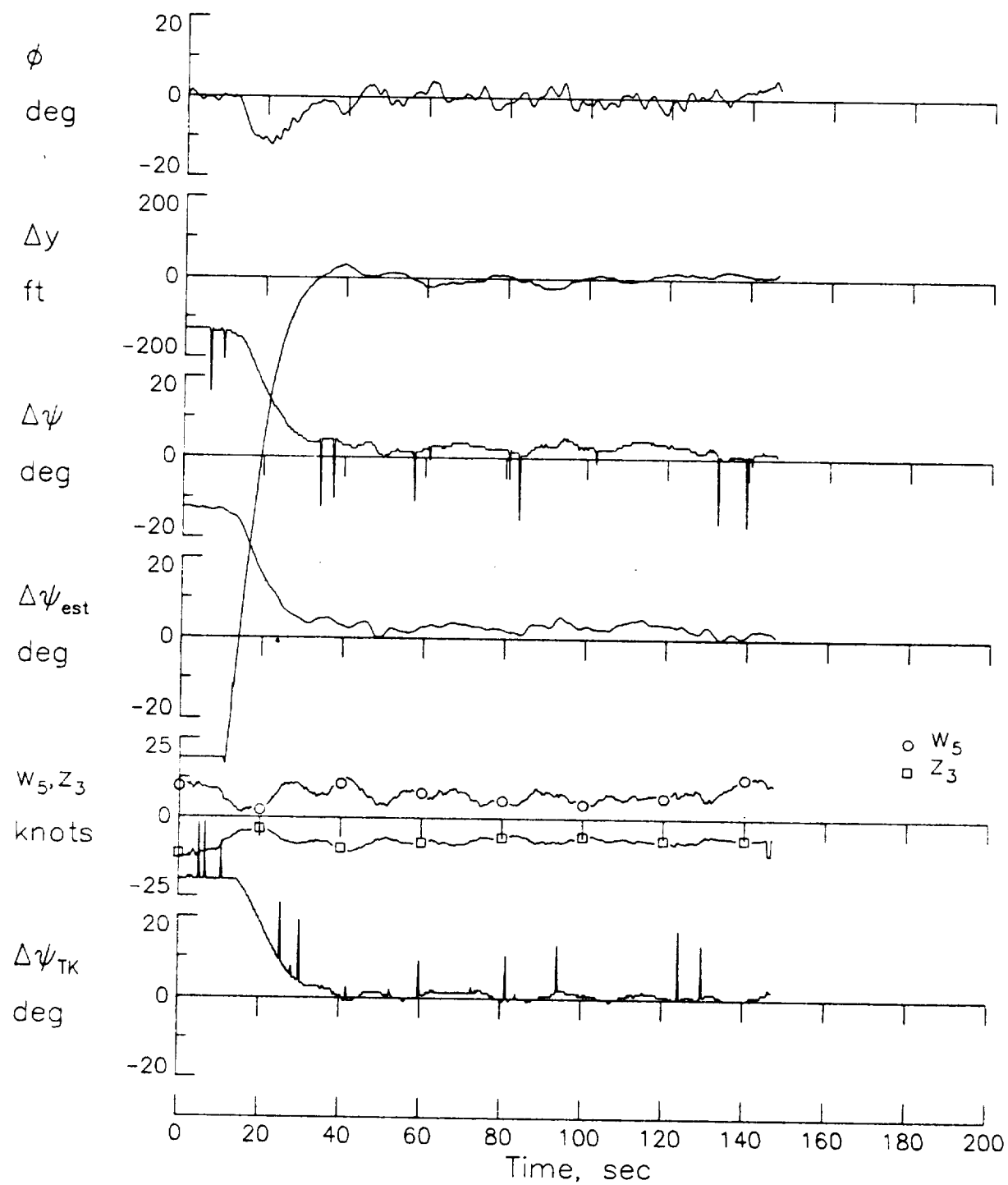


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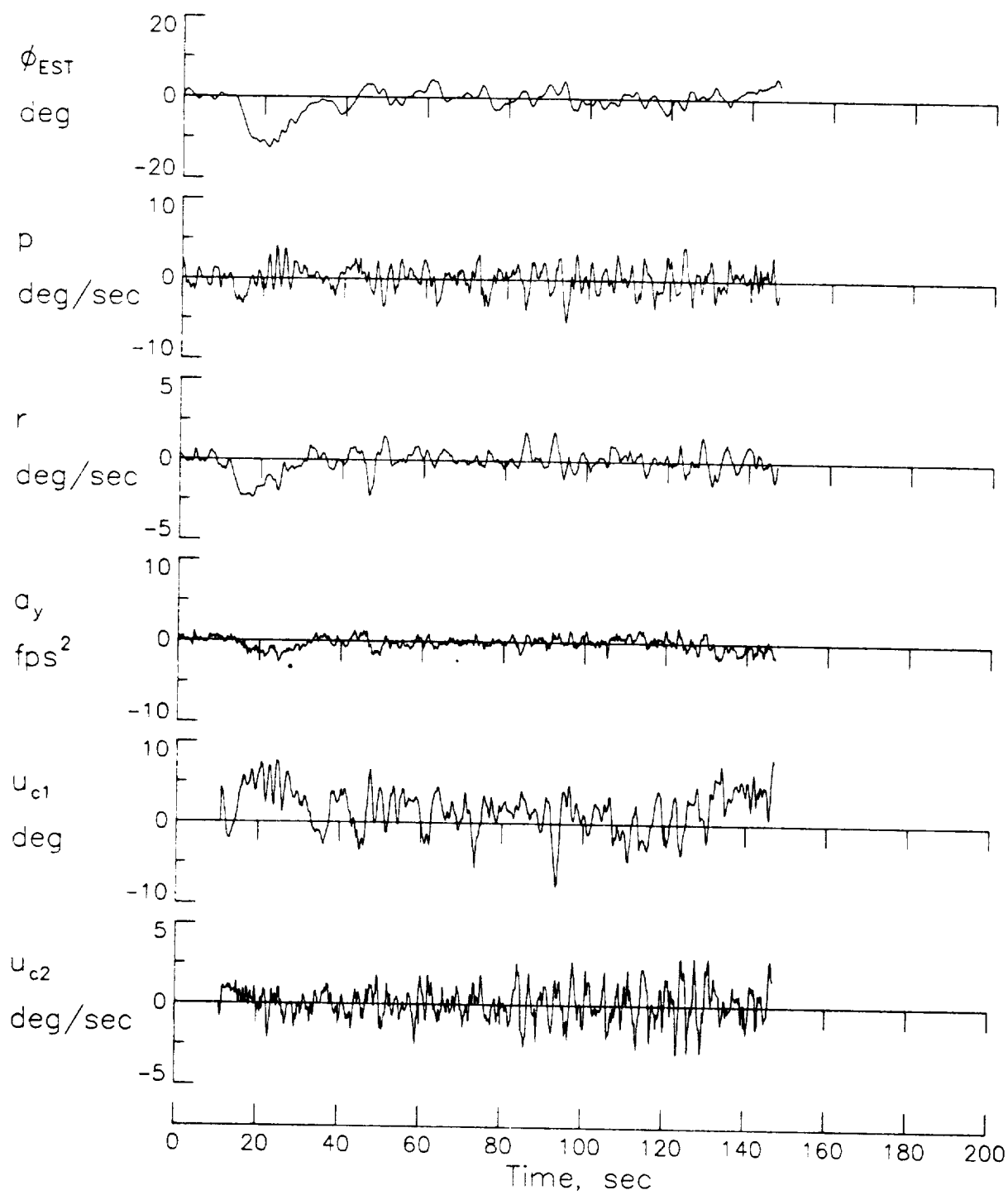


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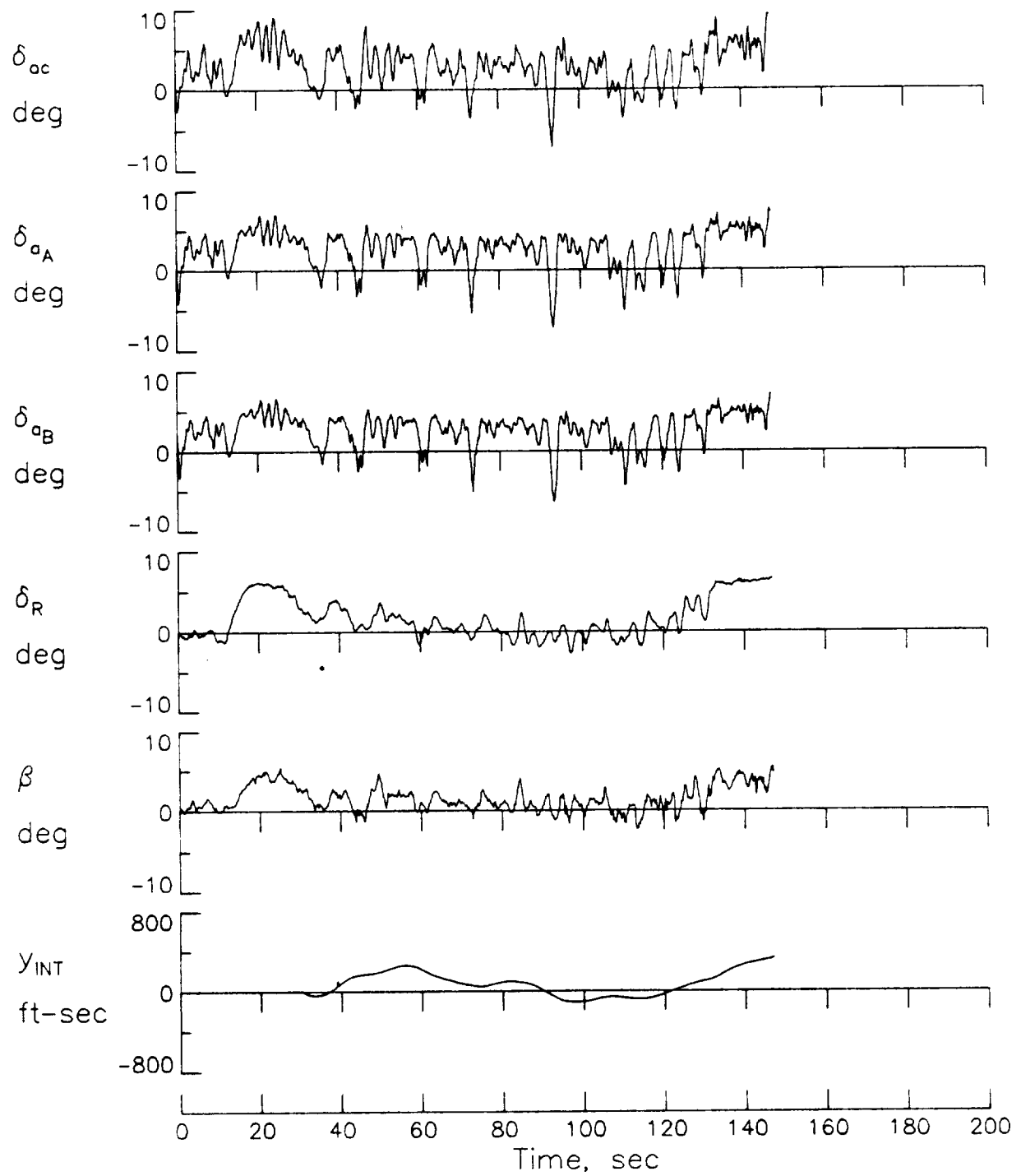


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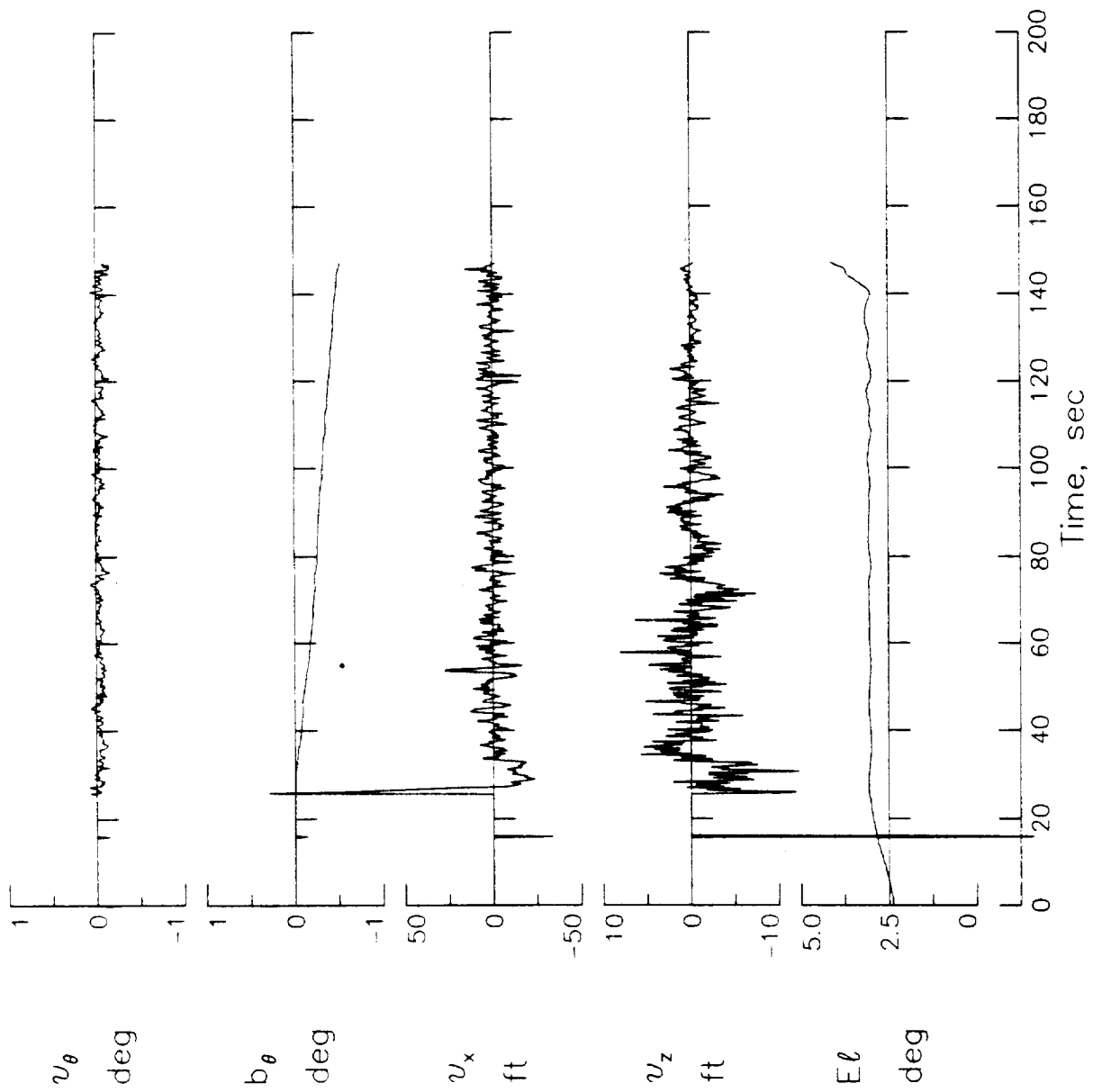


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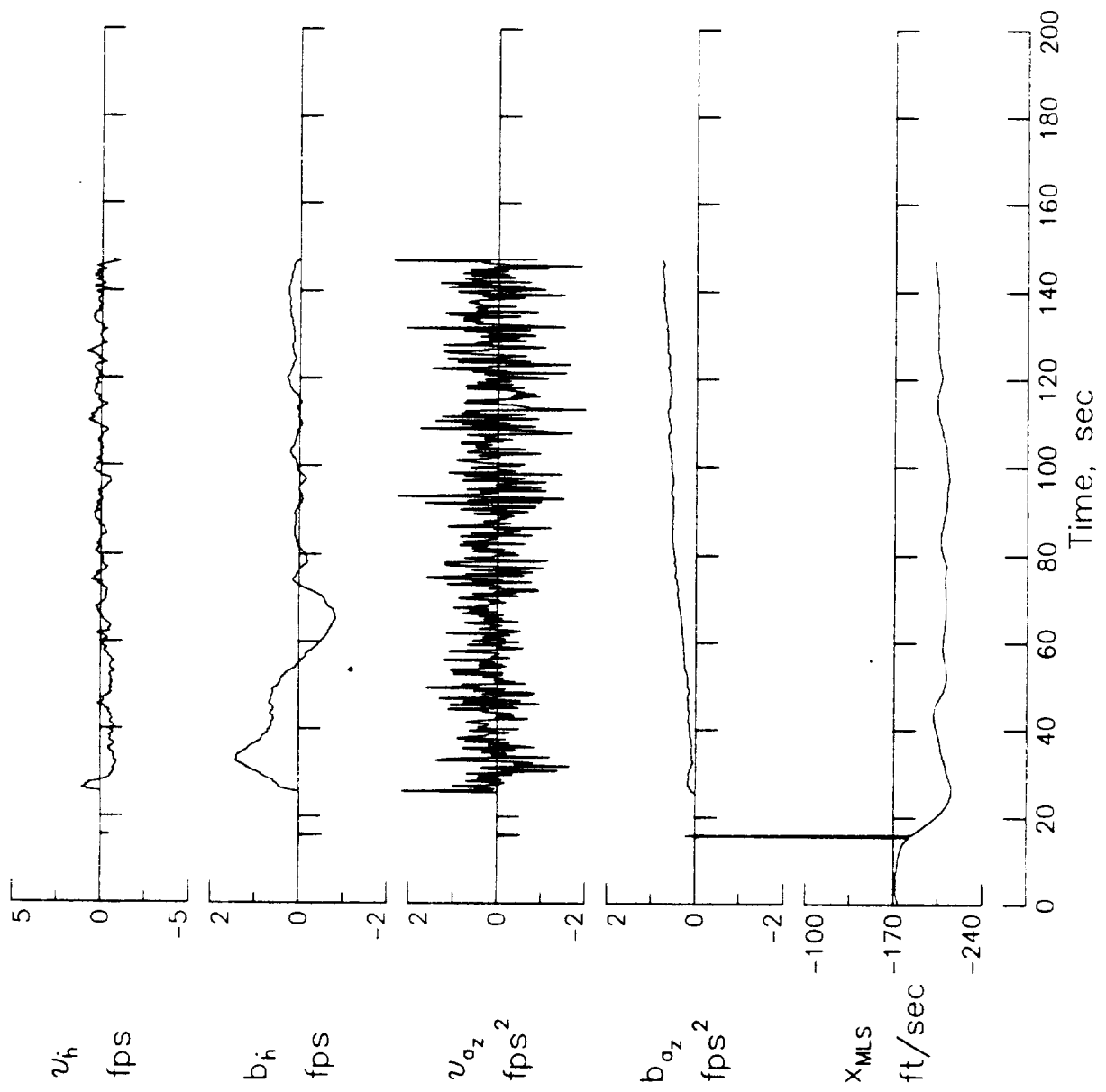


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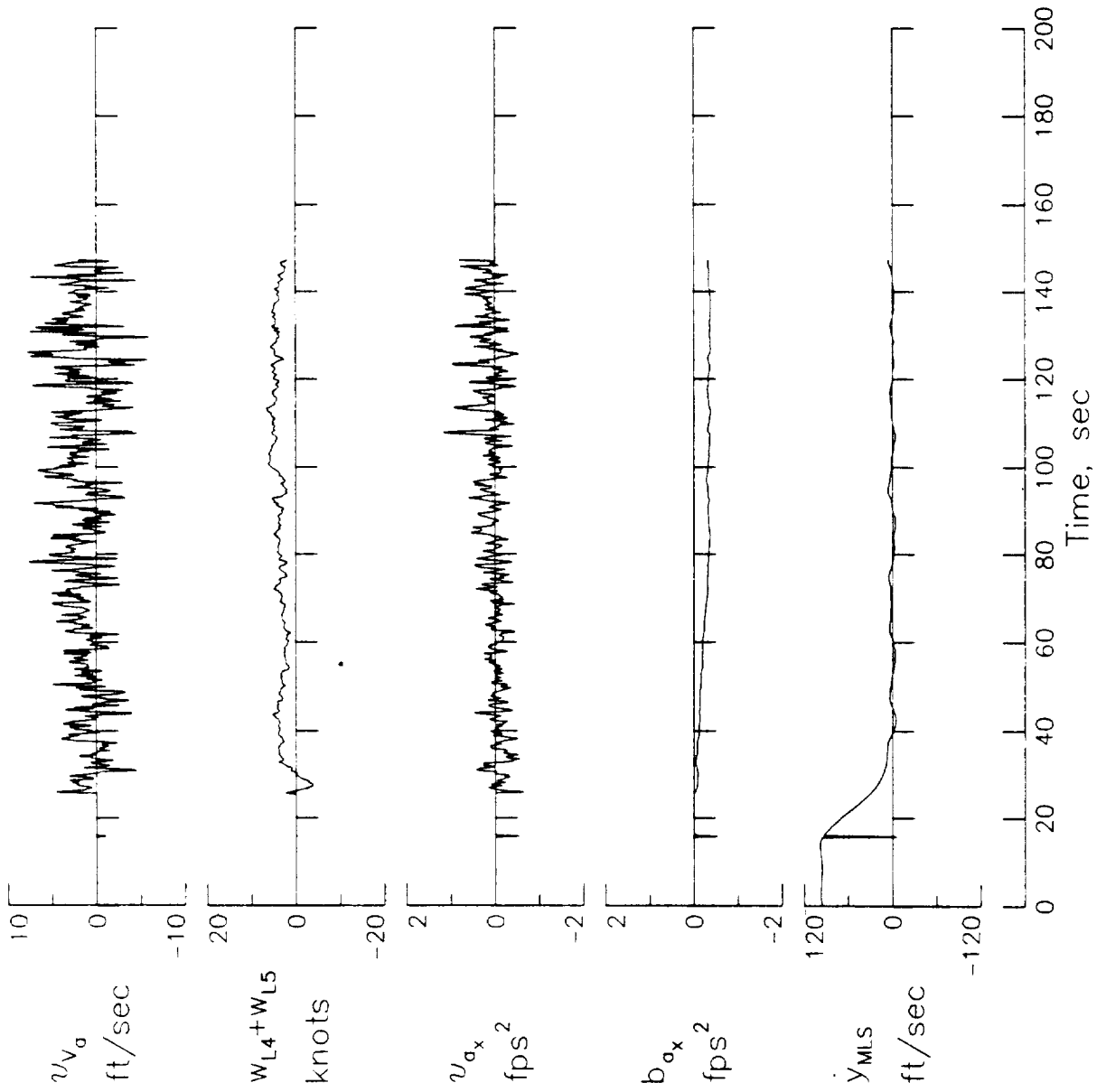


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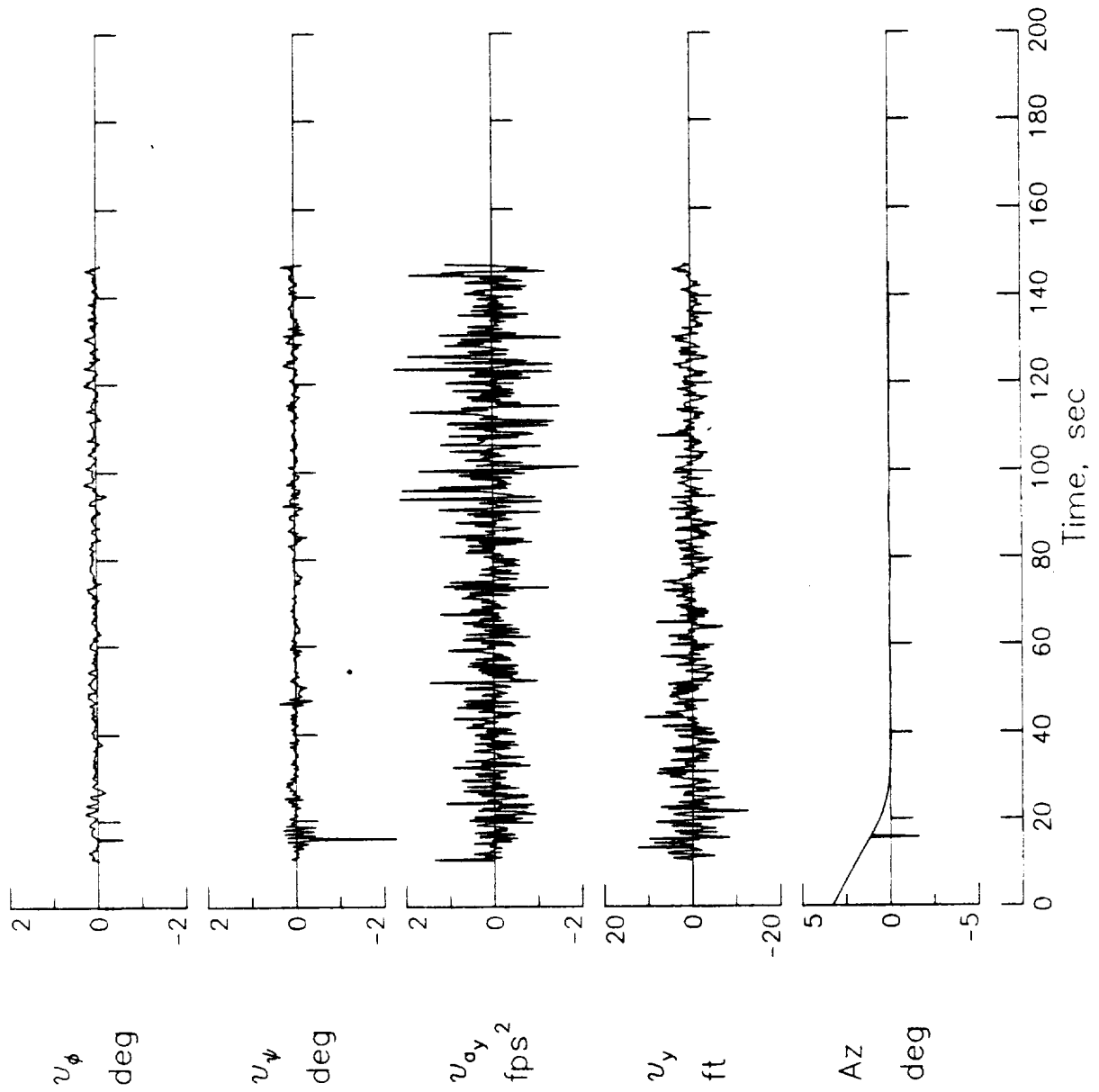


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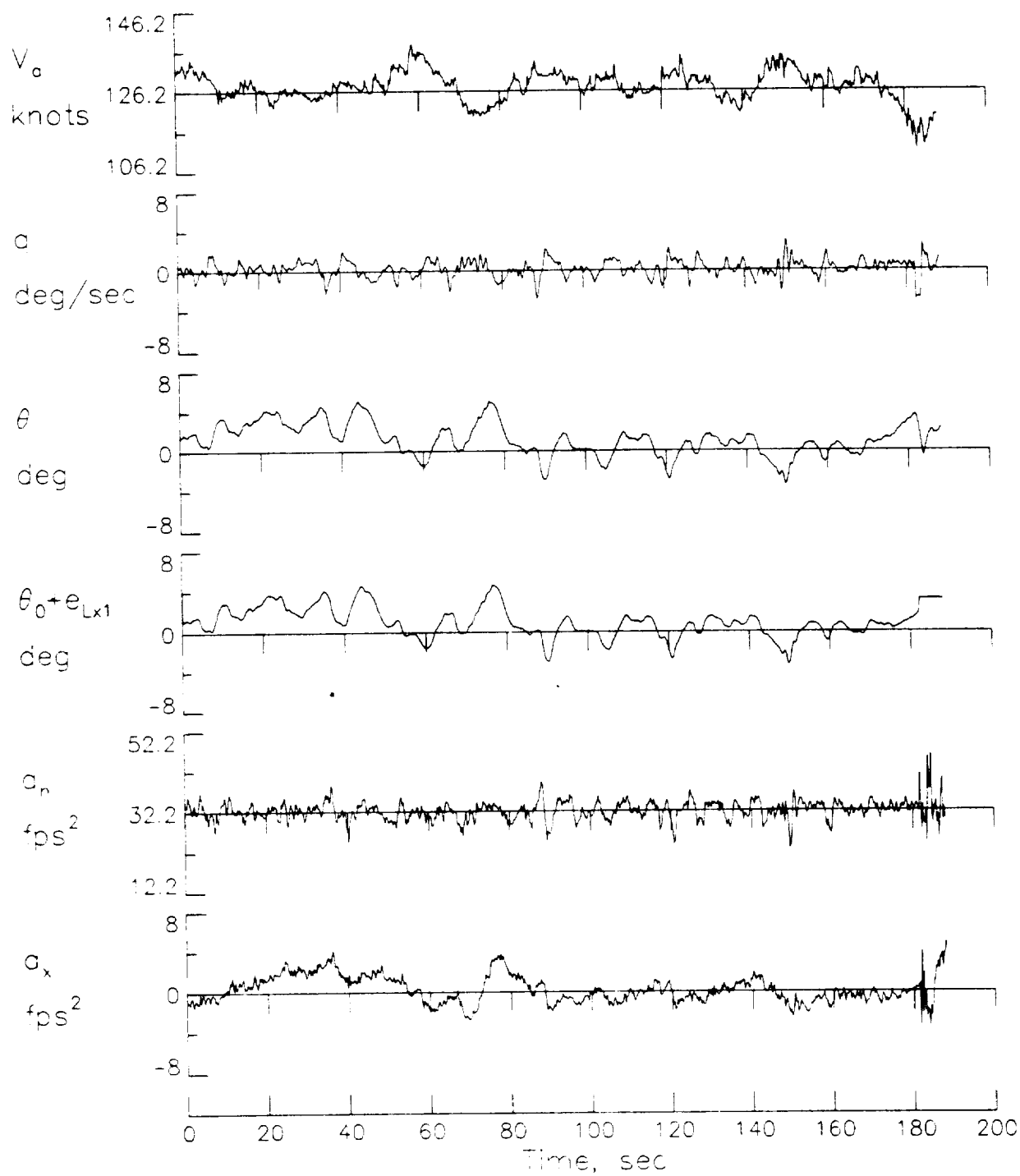


Figure 2. Flight Data for DIALS Flight Test R353, Run 6R1

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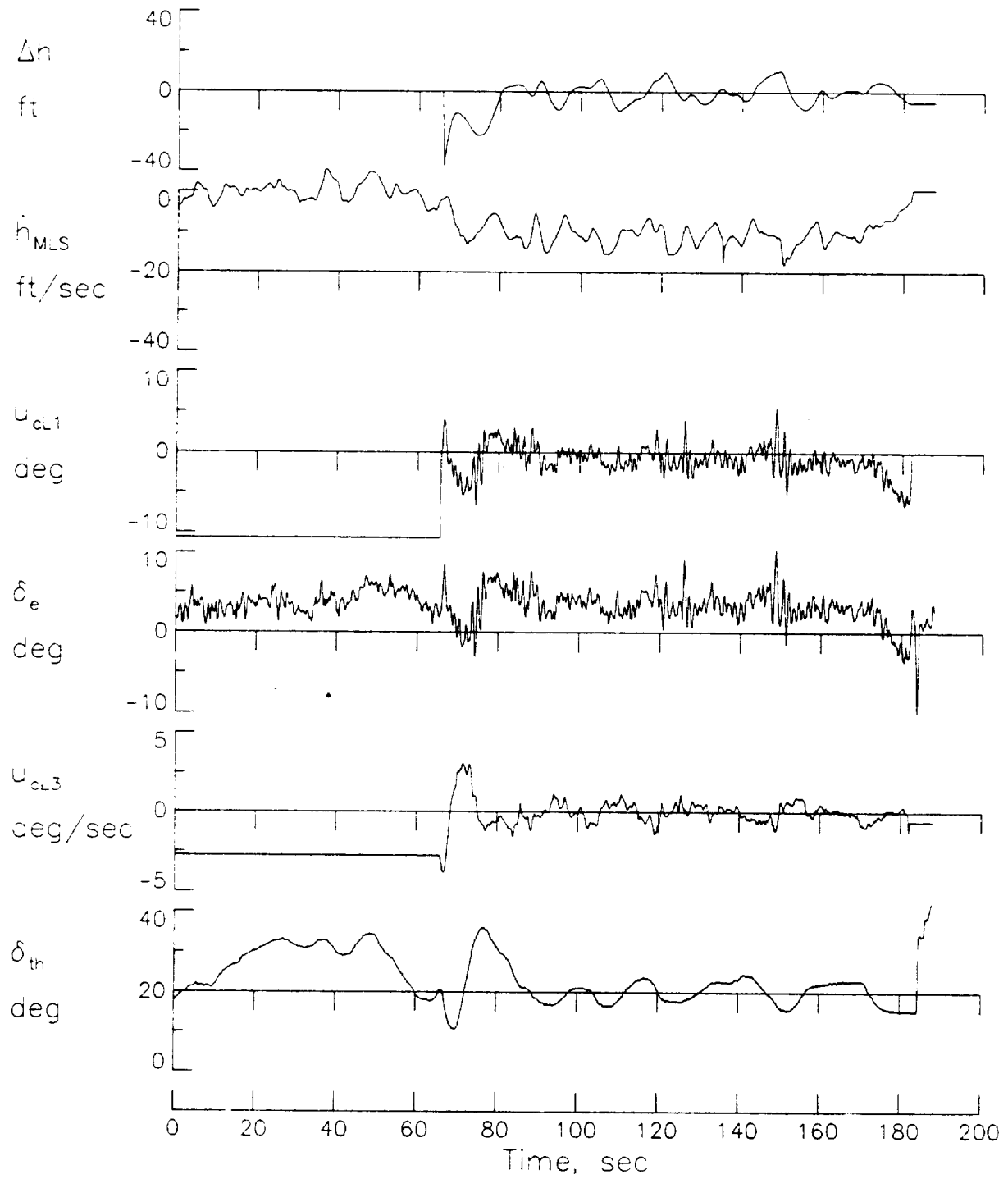


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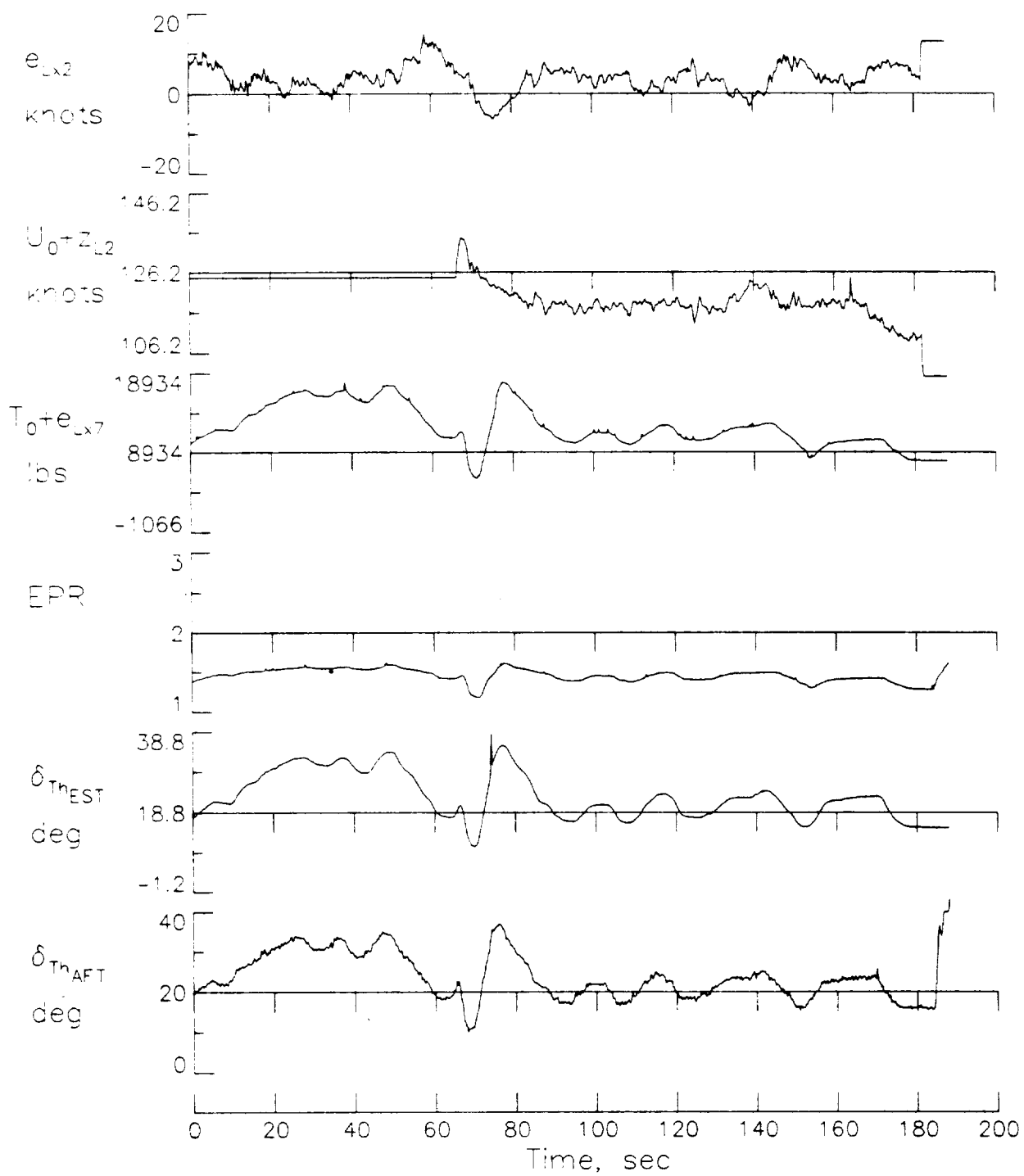


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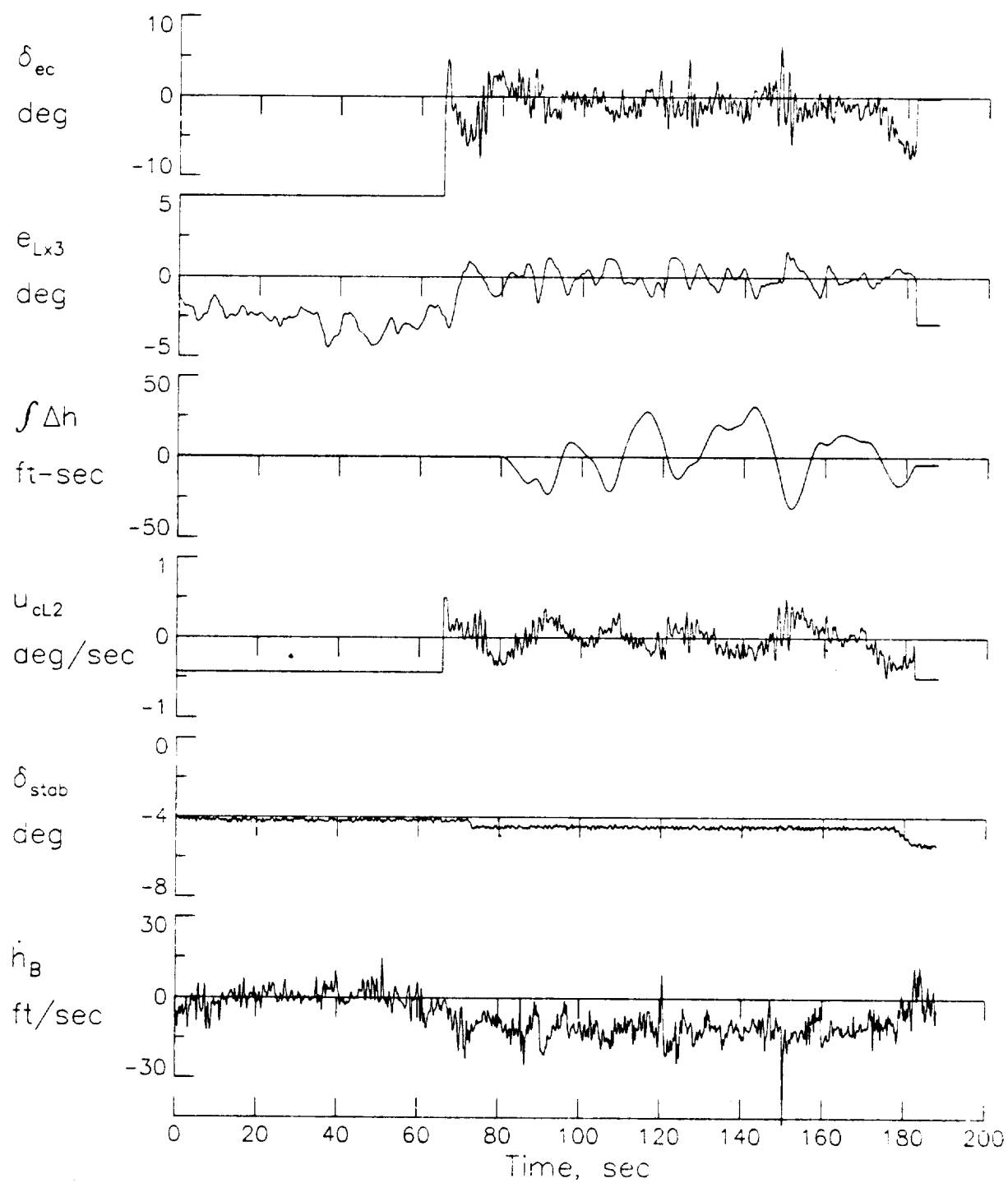


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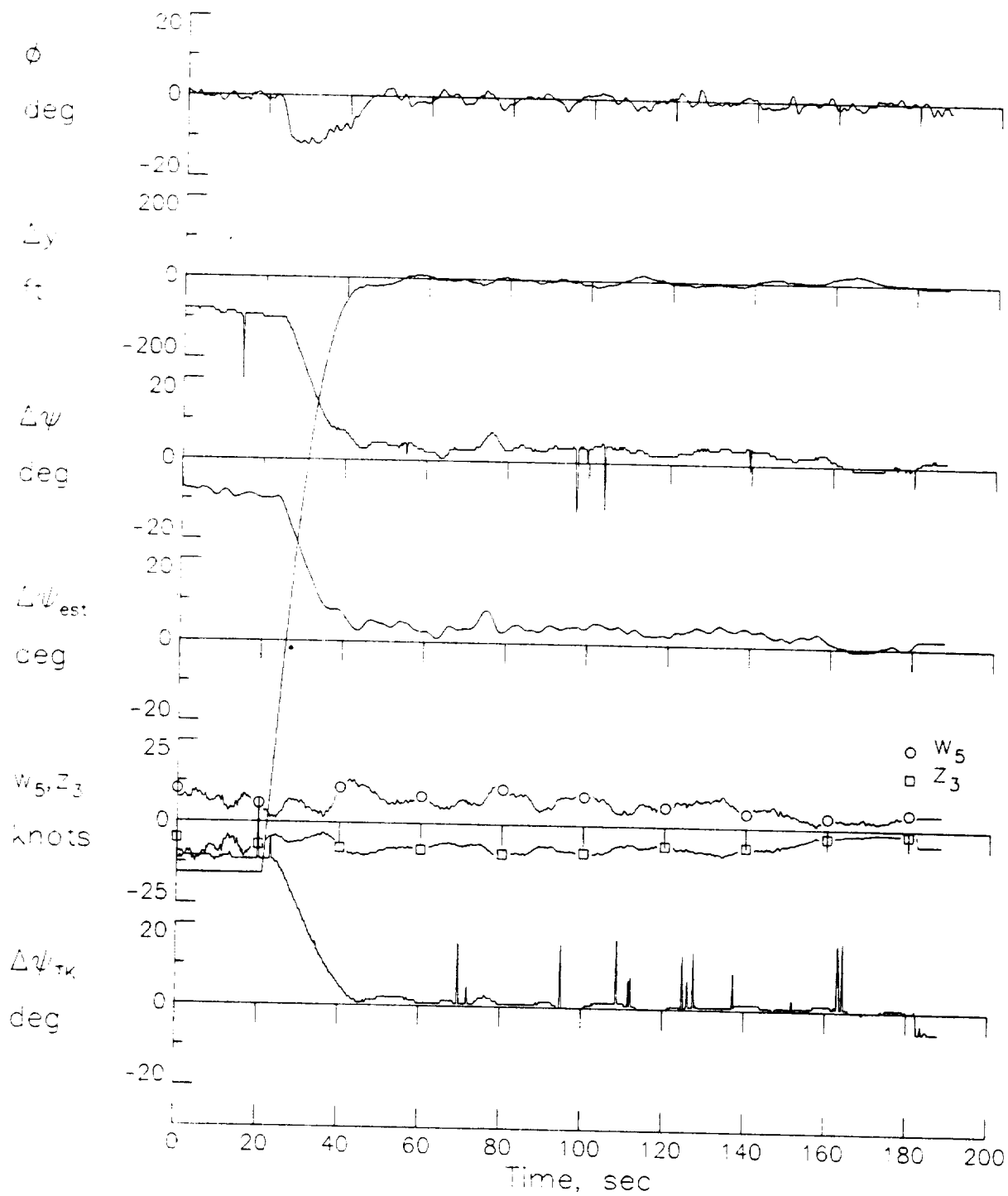


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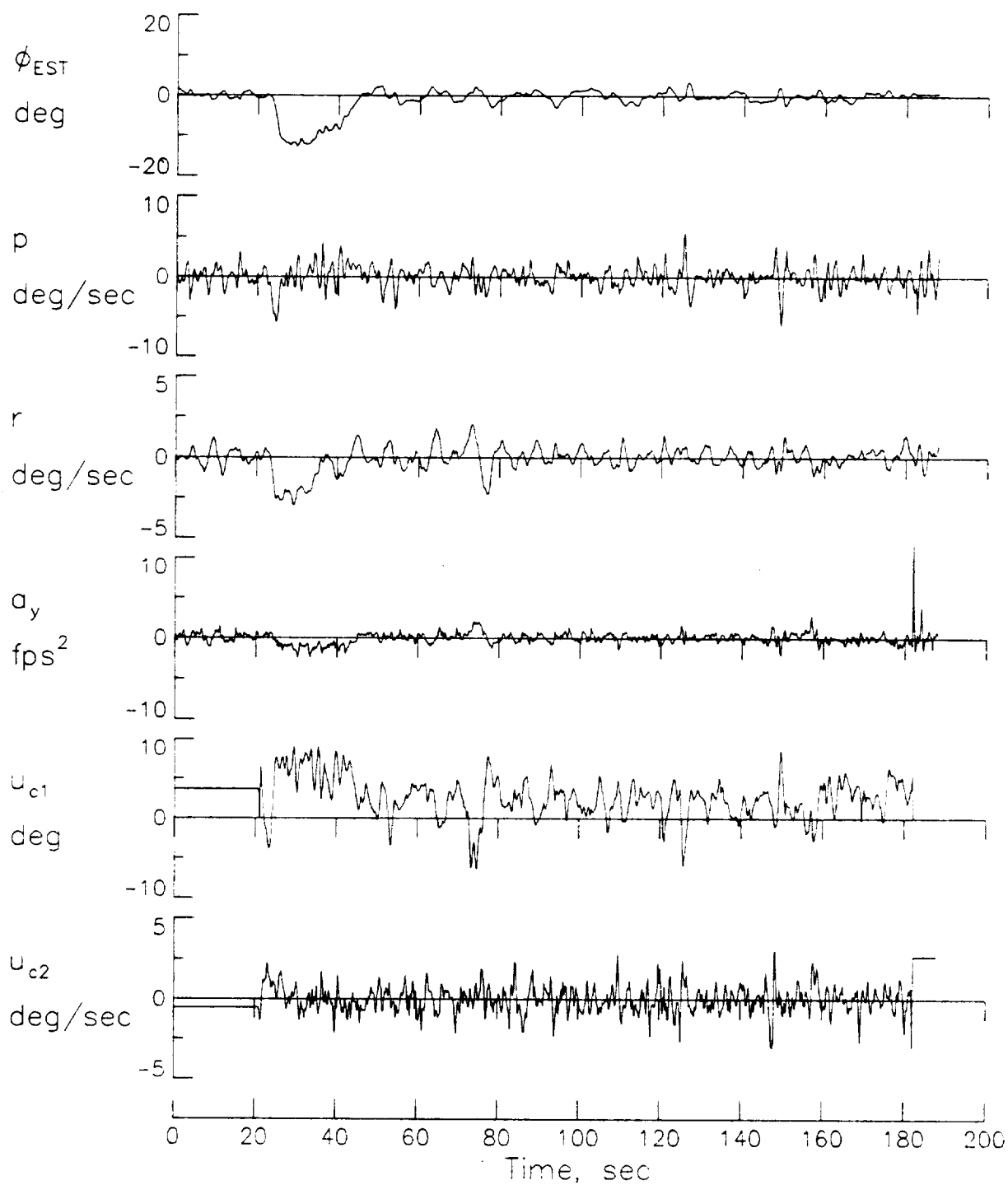


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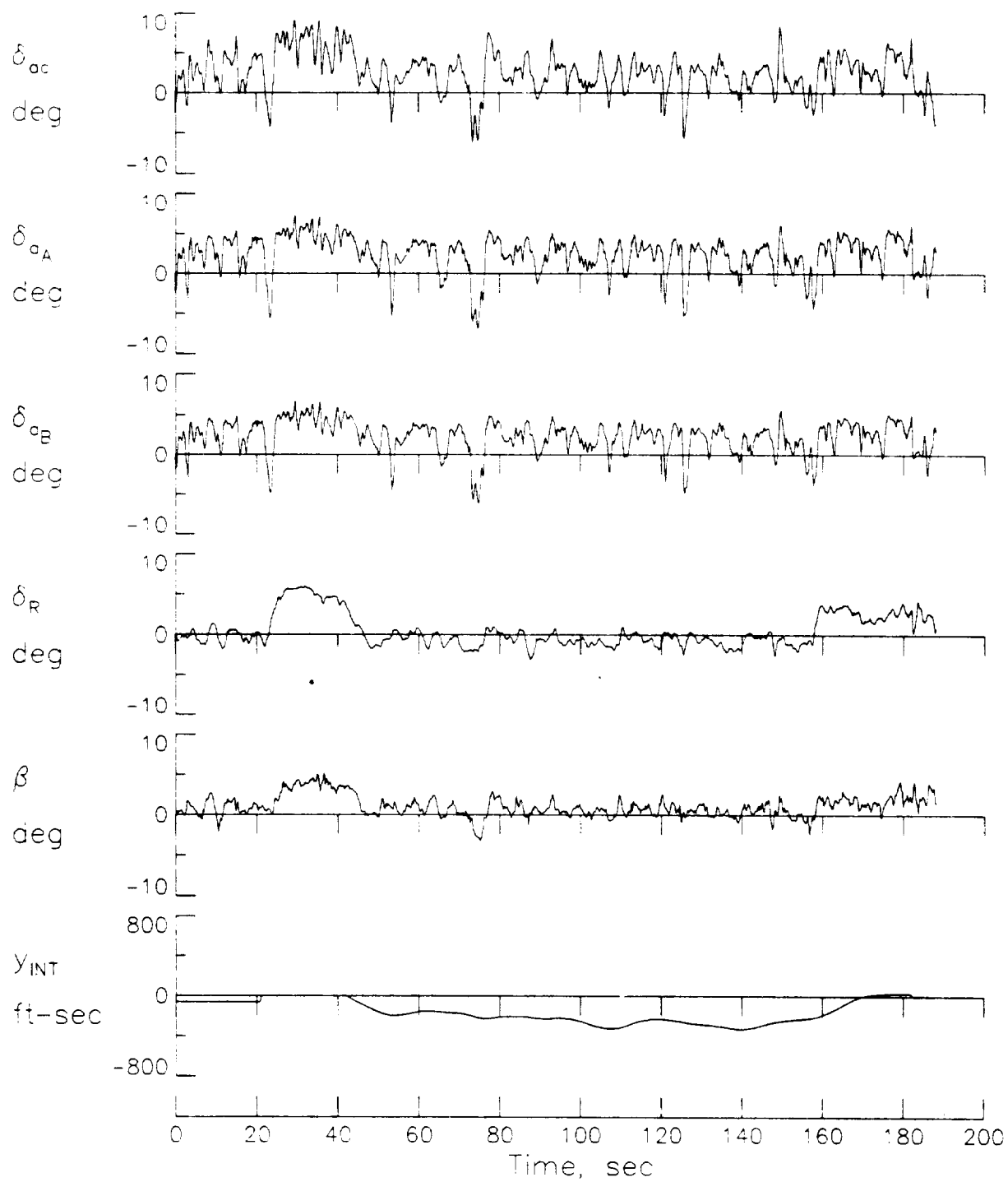


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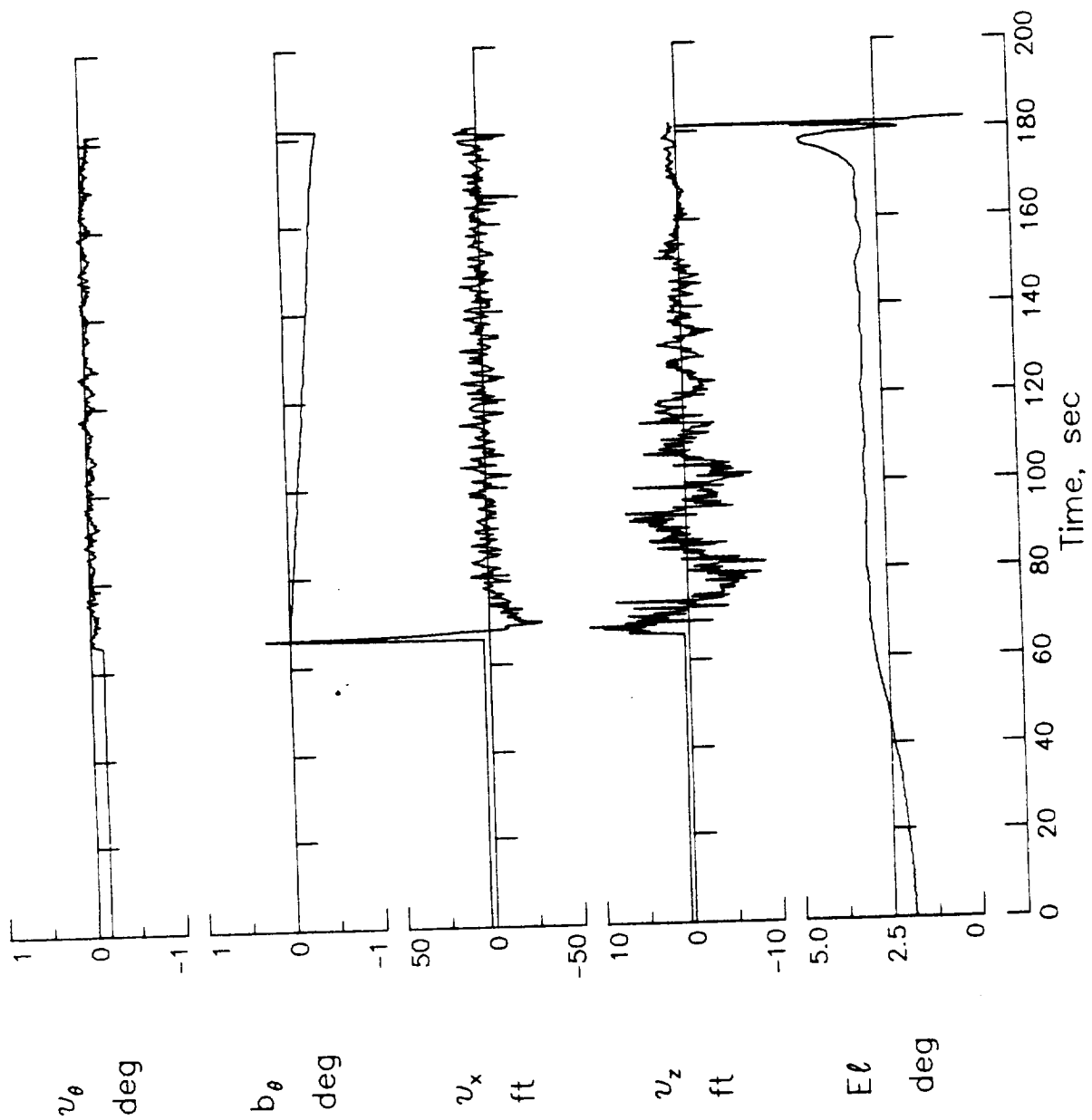


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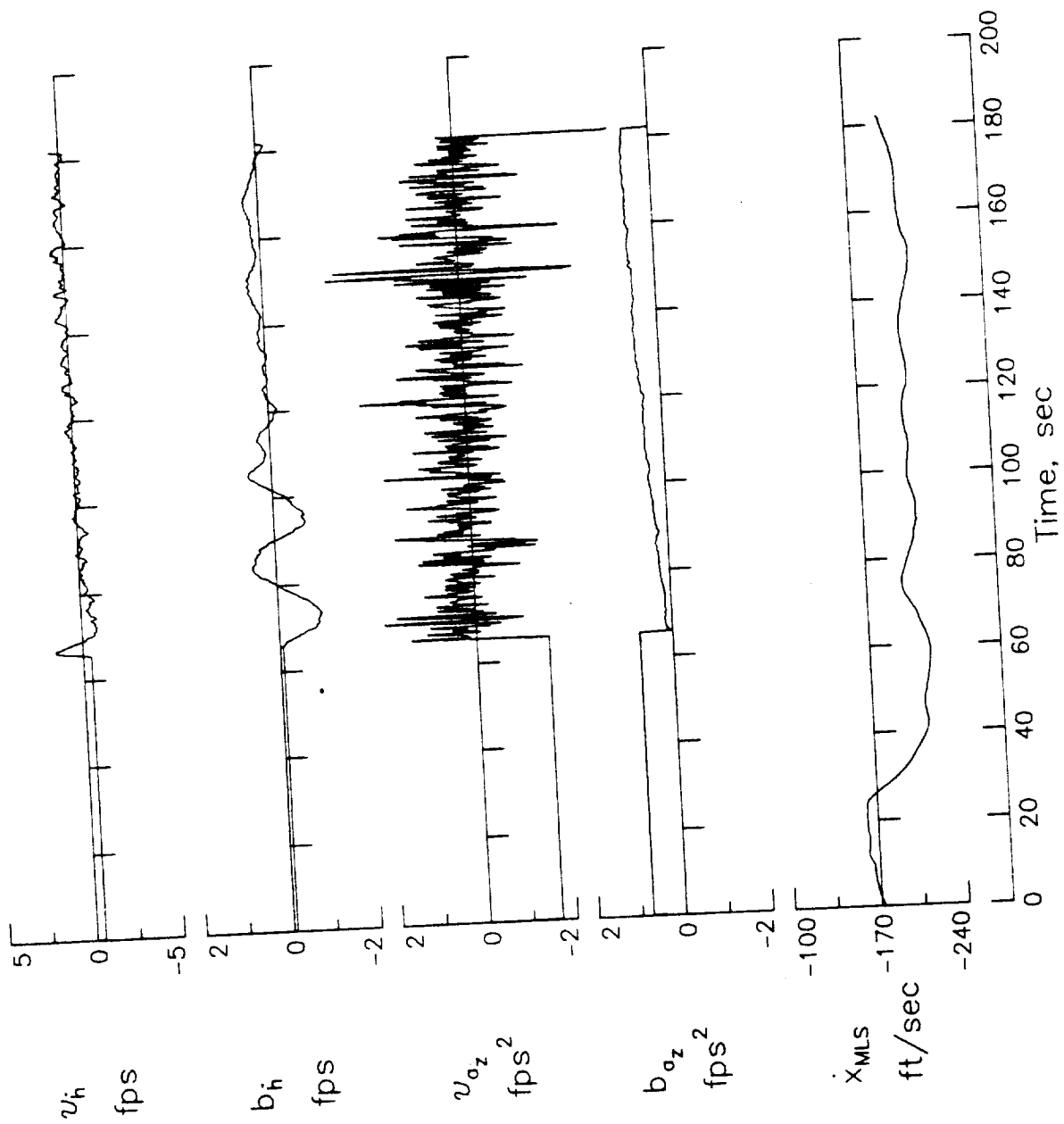


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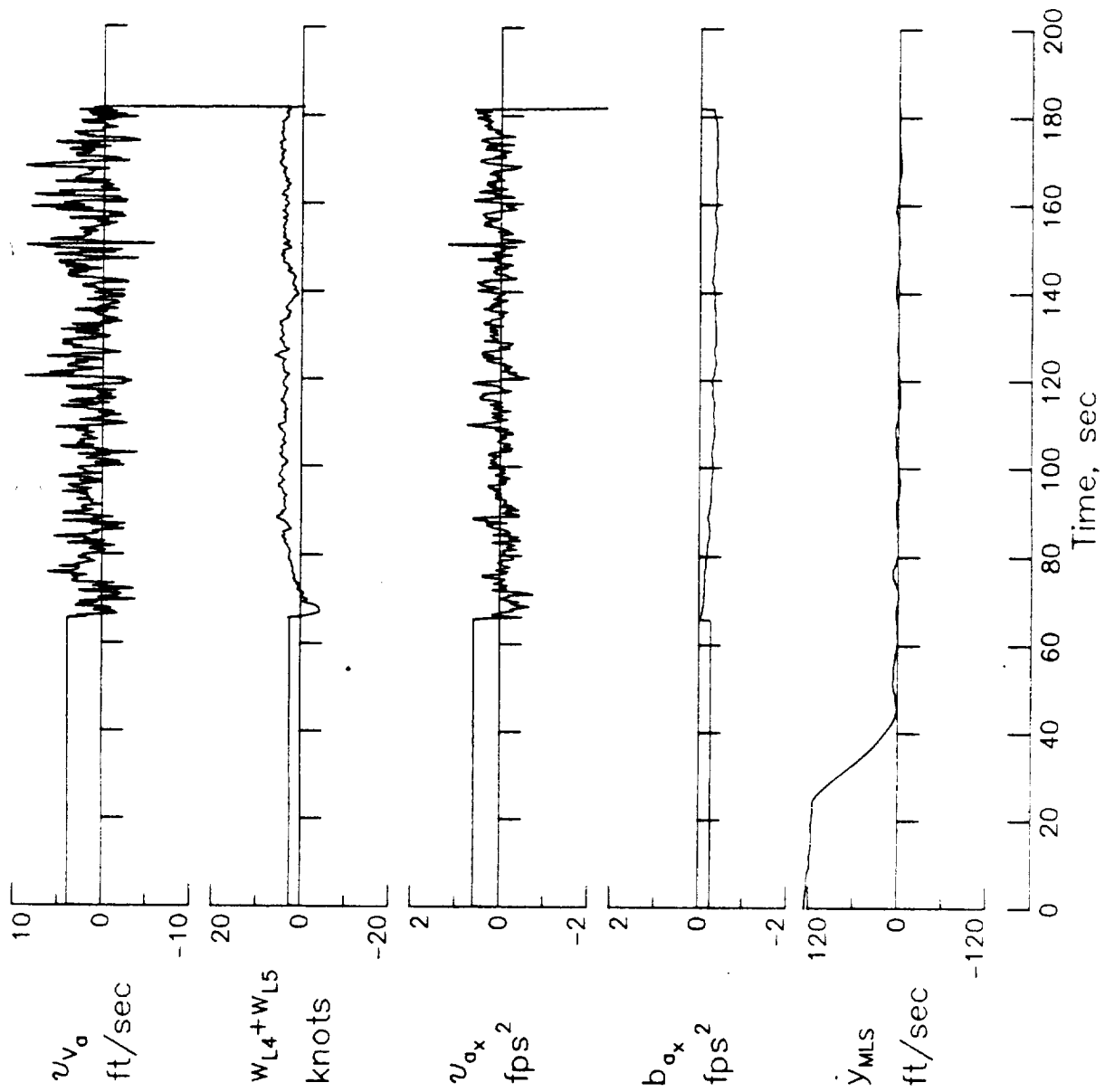


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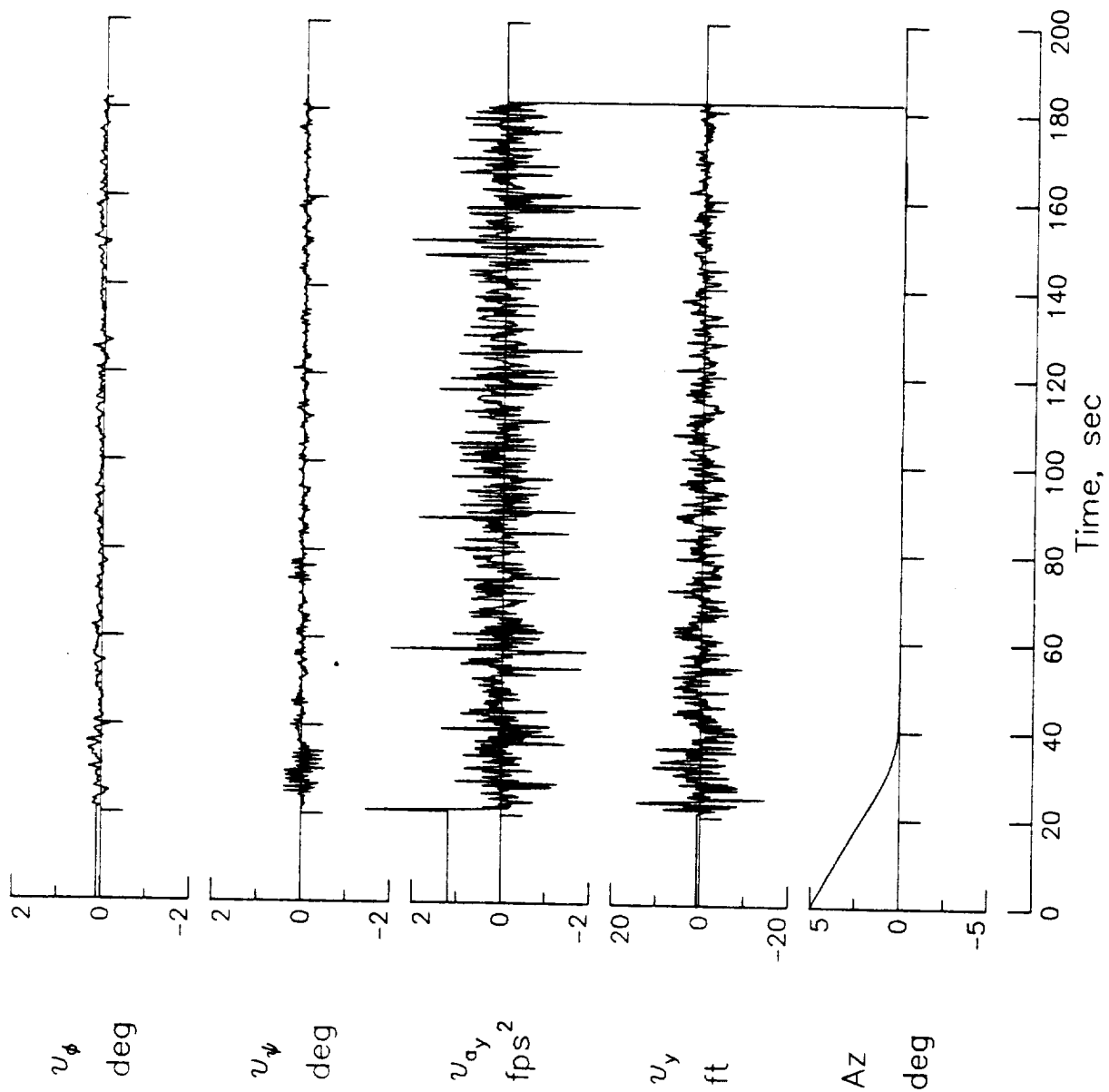


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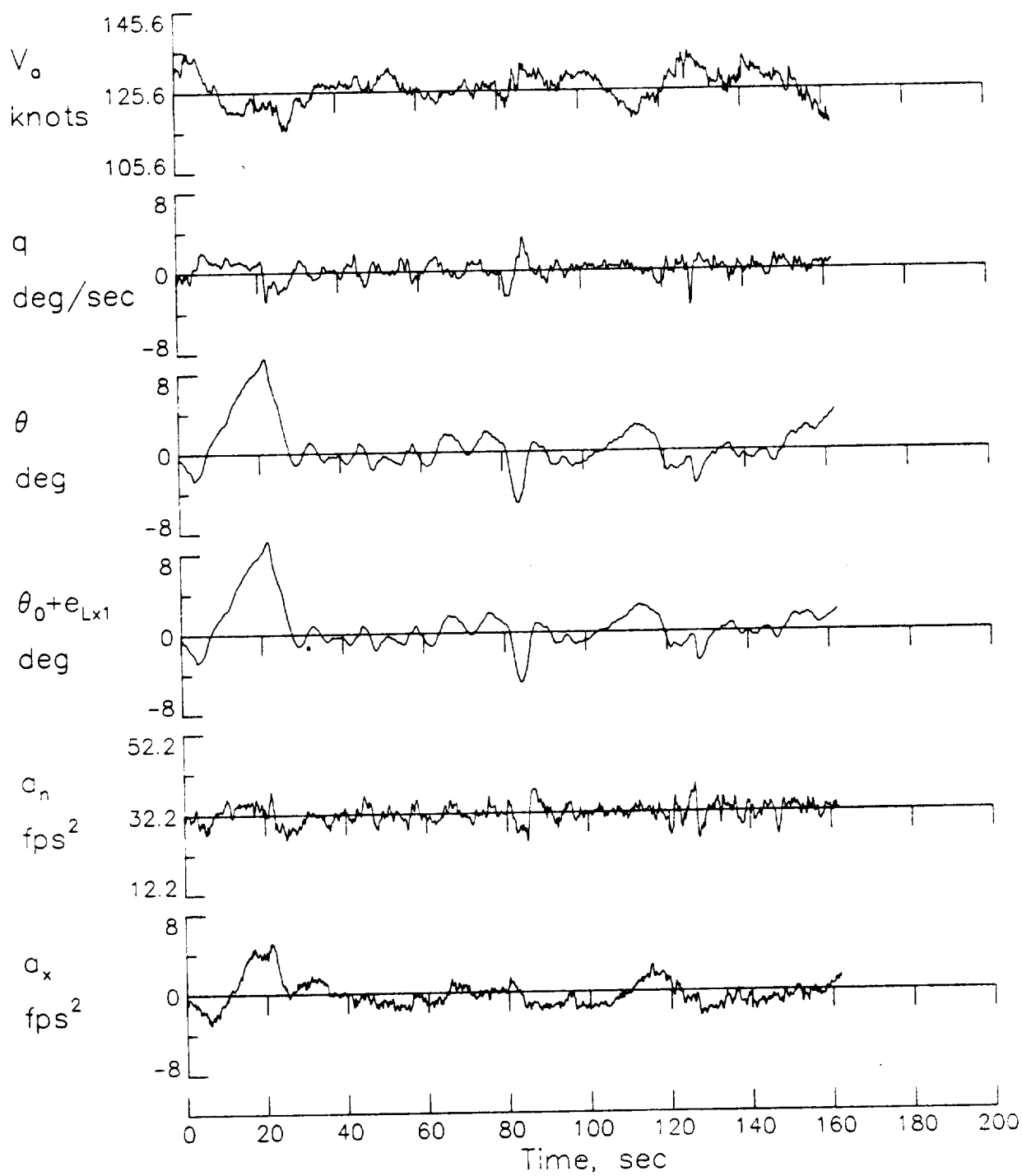


Figure 3. Flight Test Data for DIALS Flight Test R353, Run 6R2

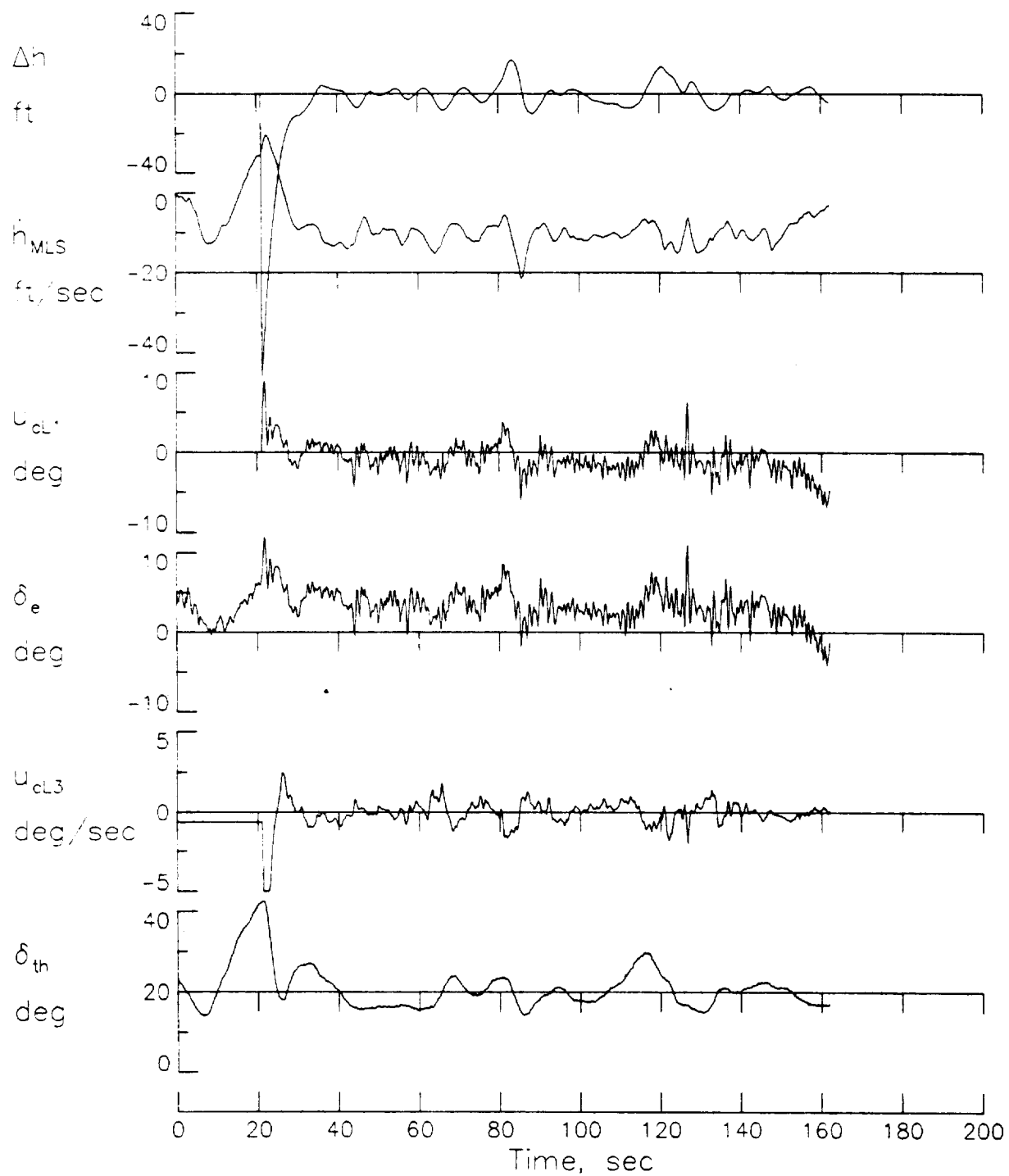


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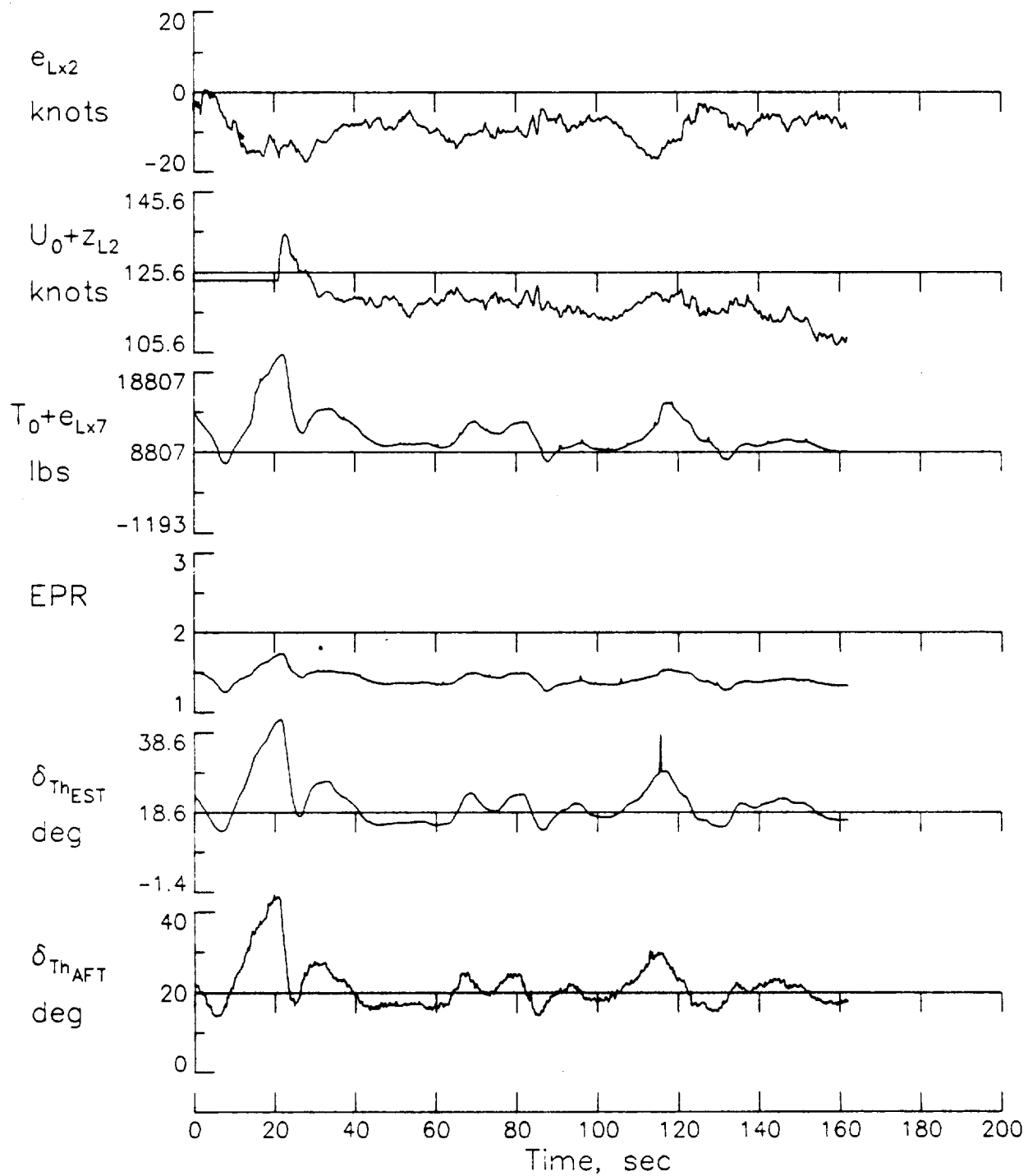


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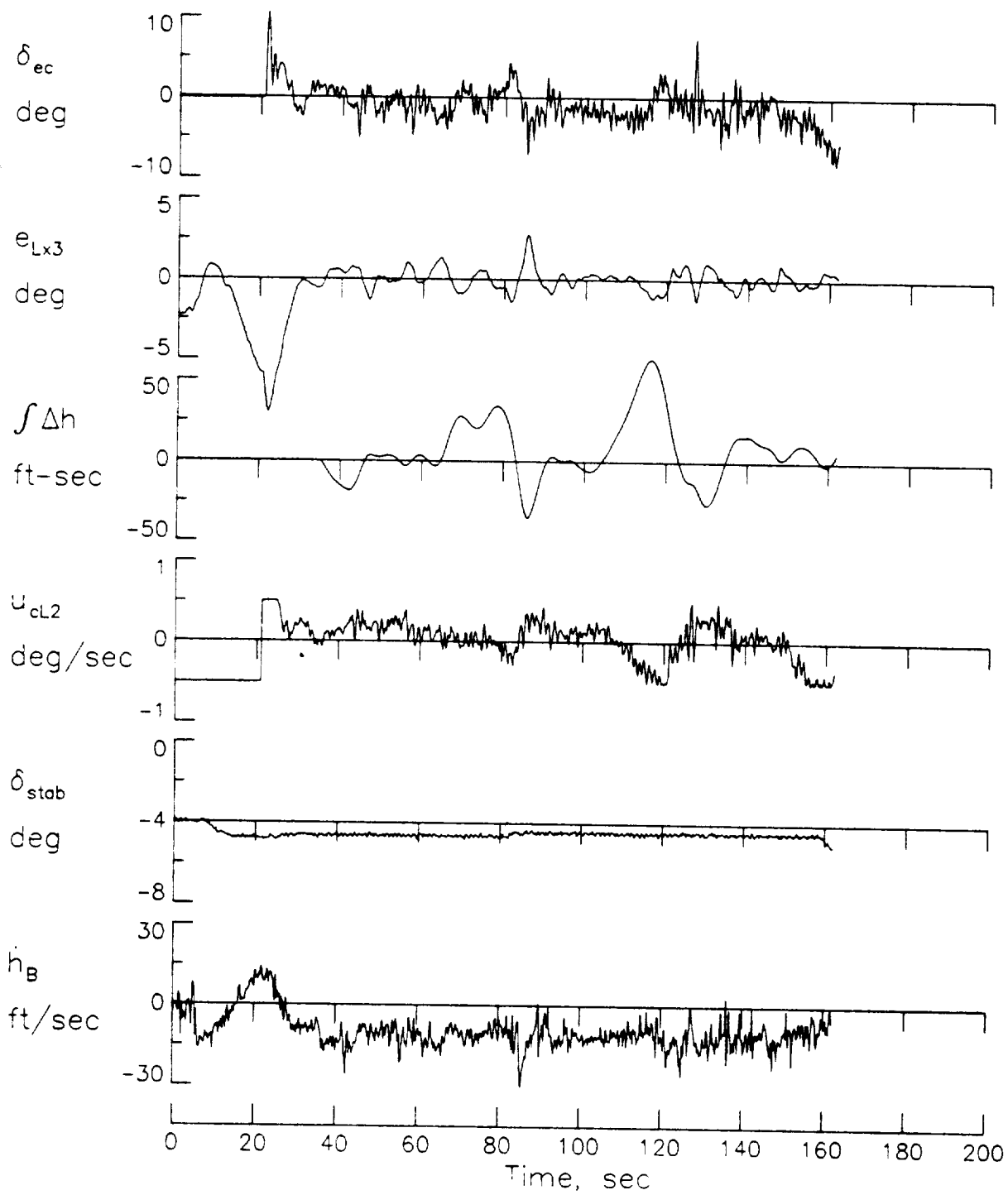


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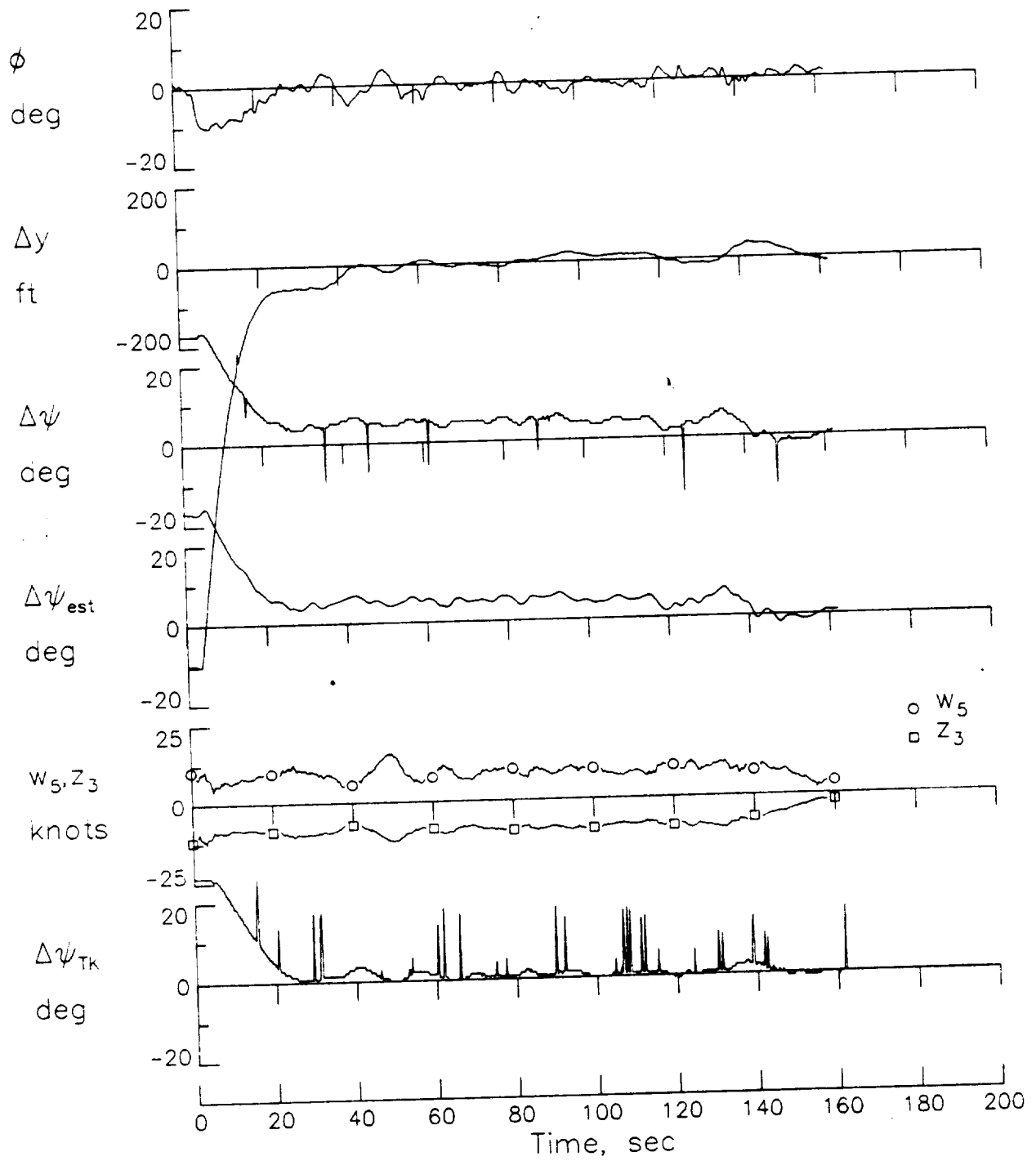


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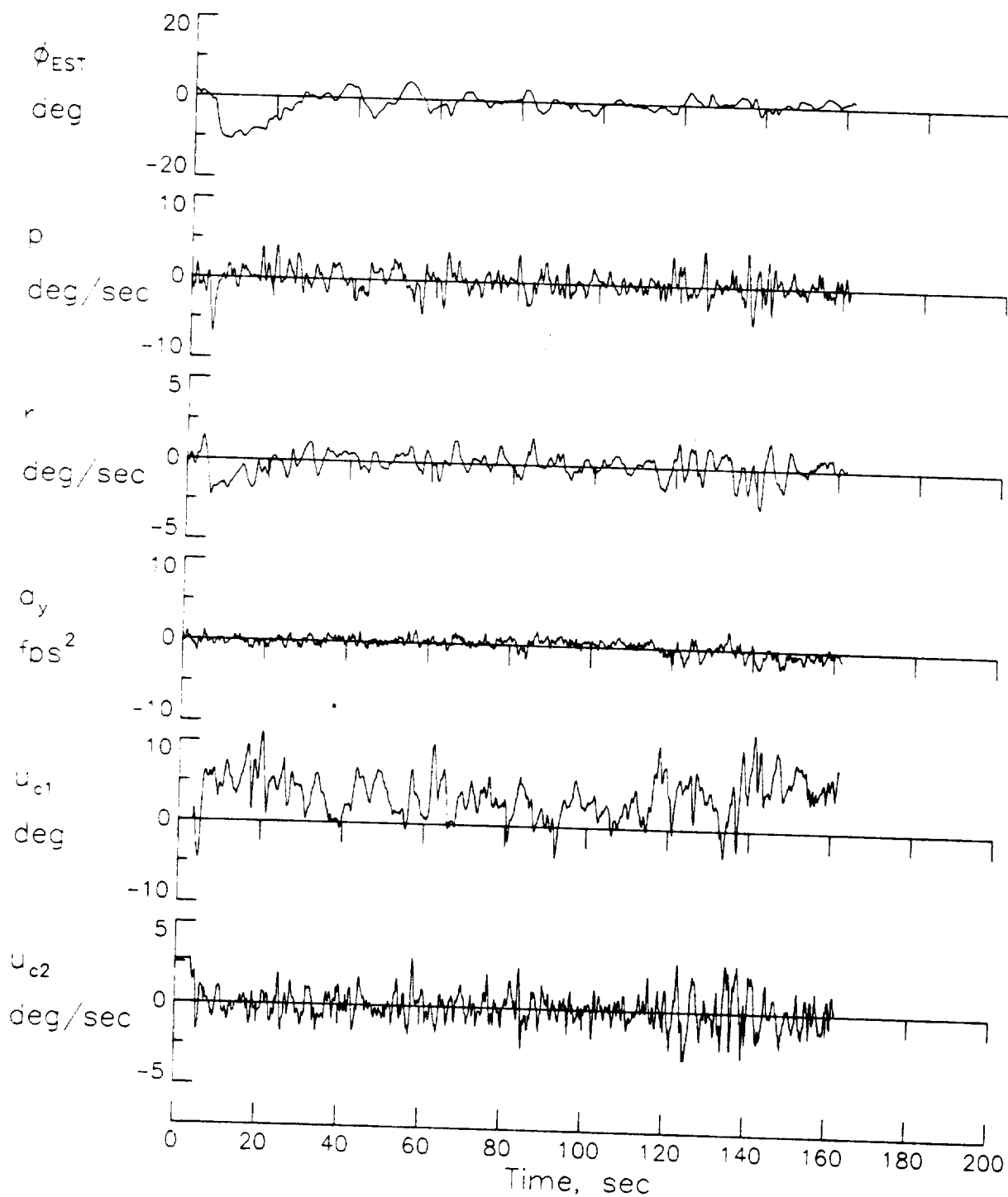


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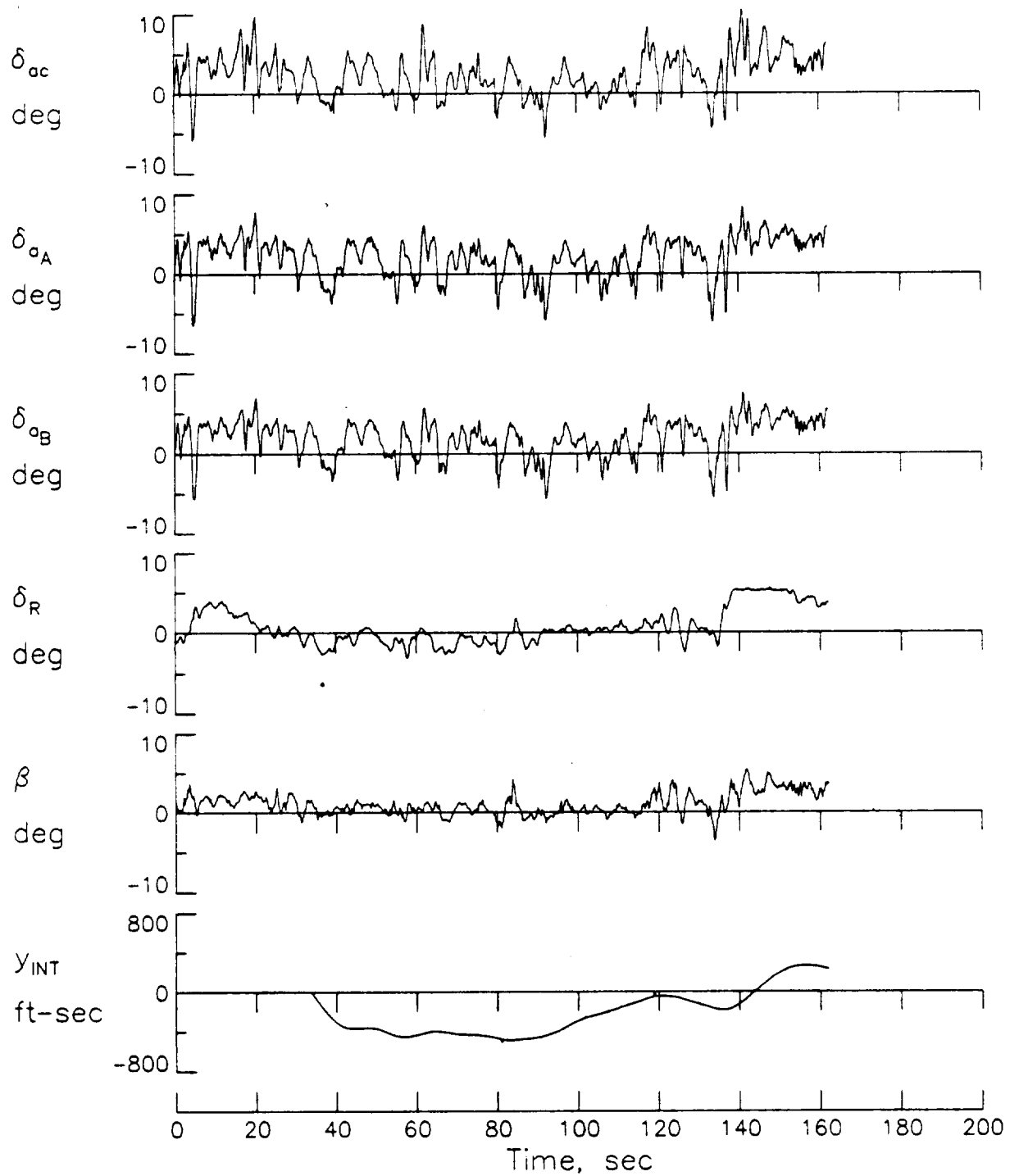


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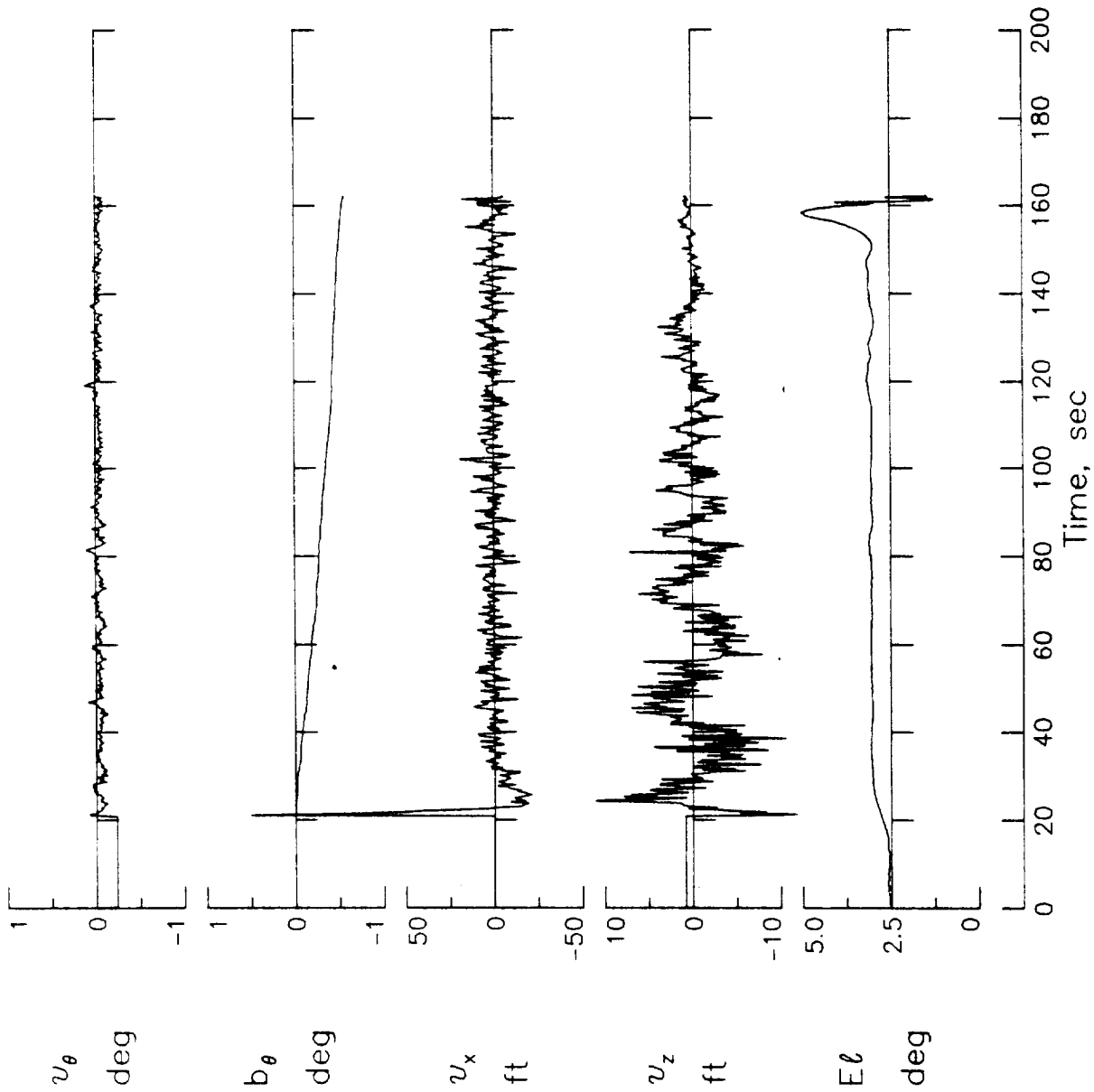


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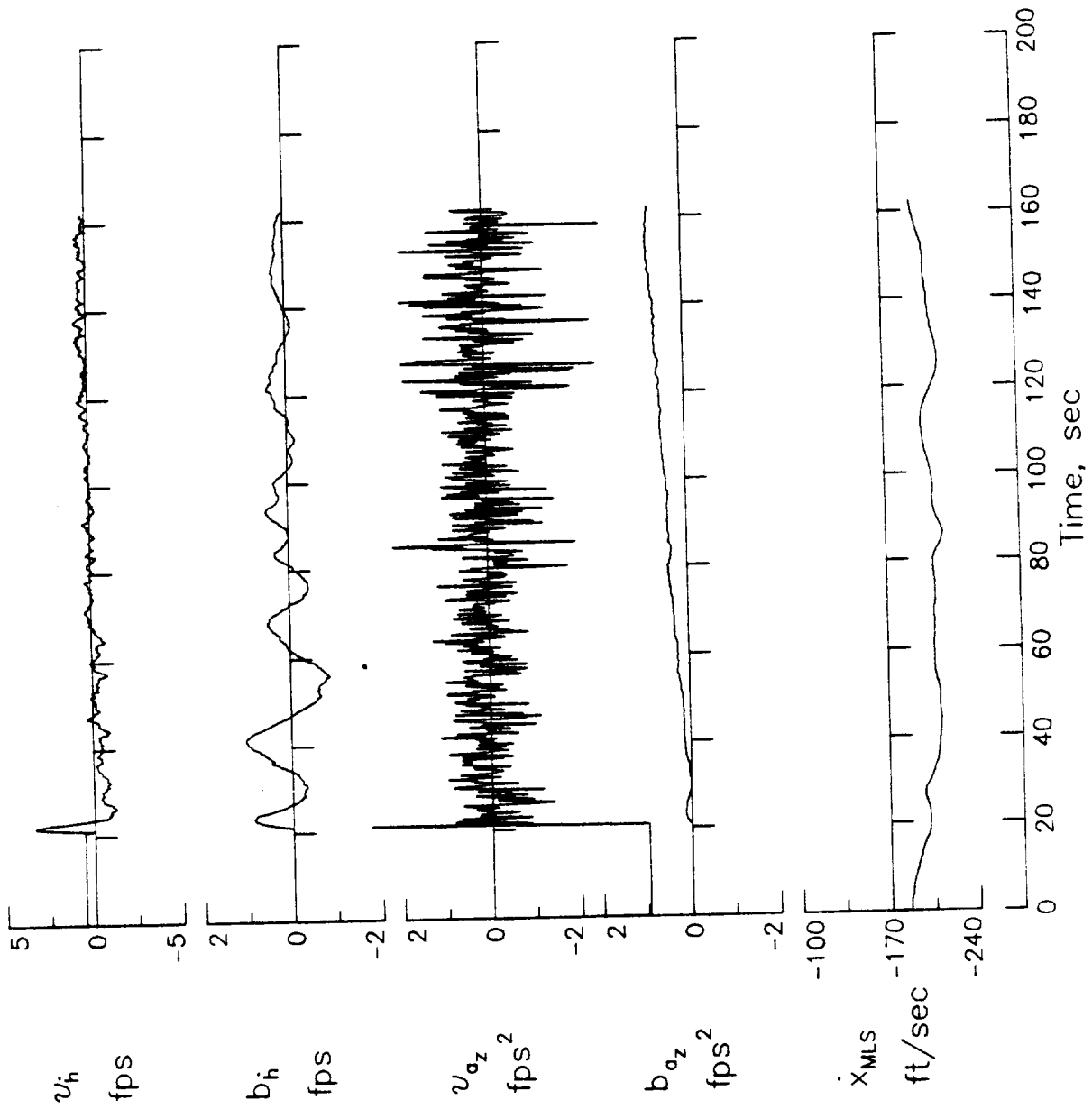


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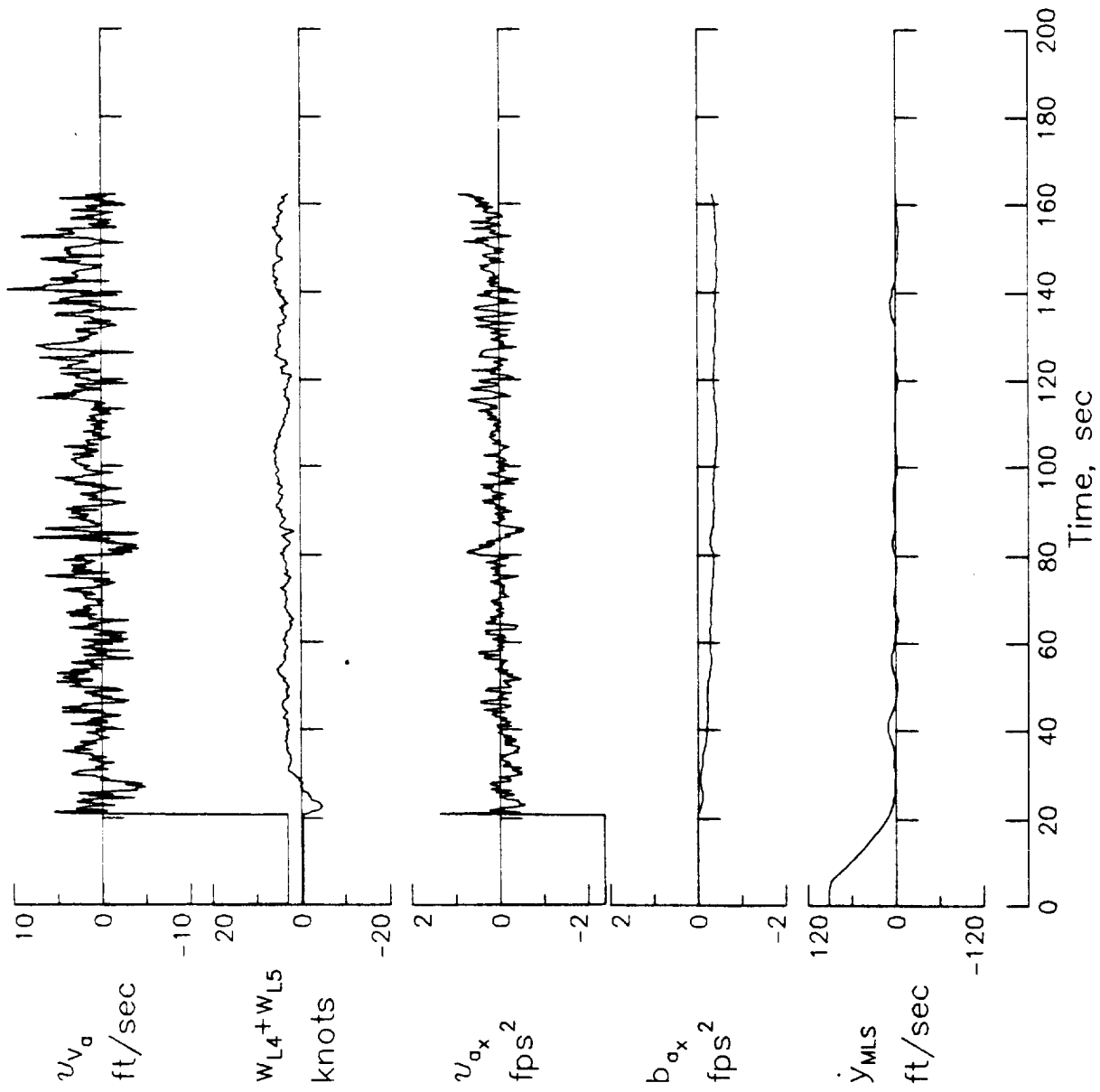


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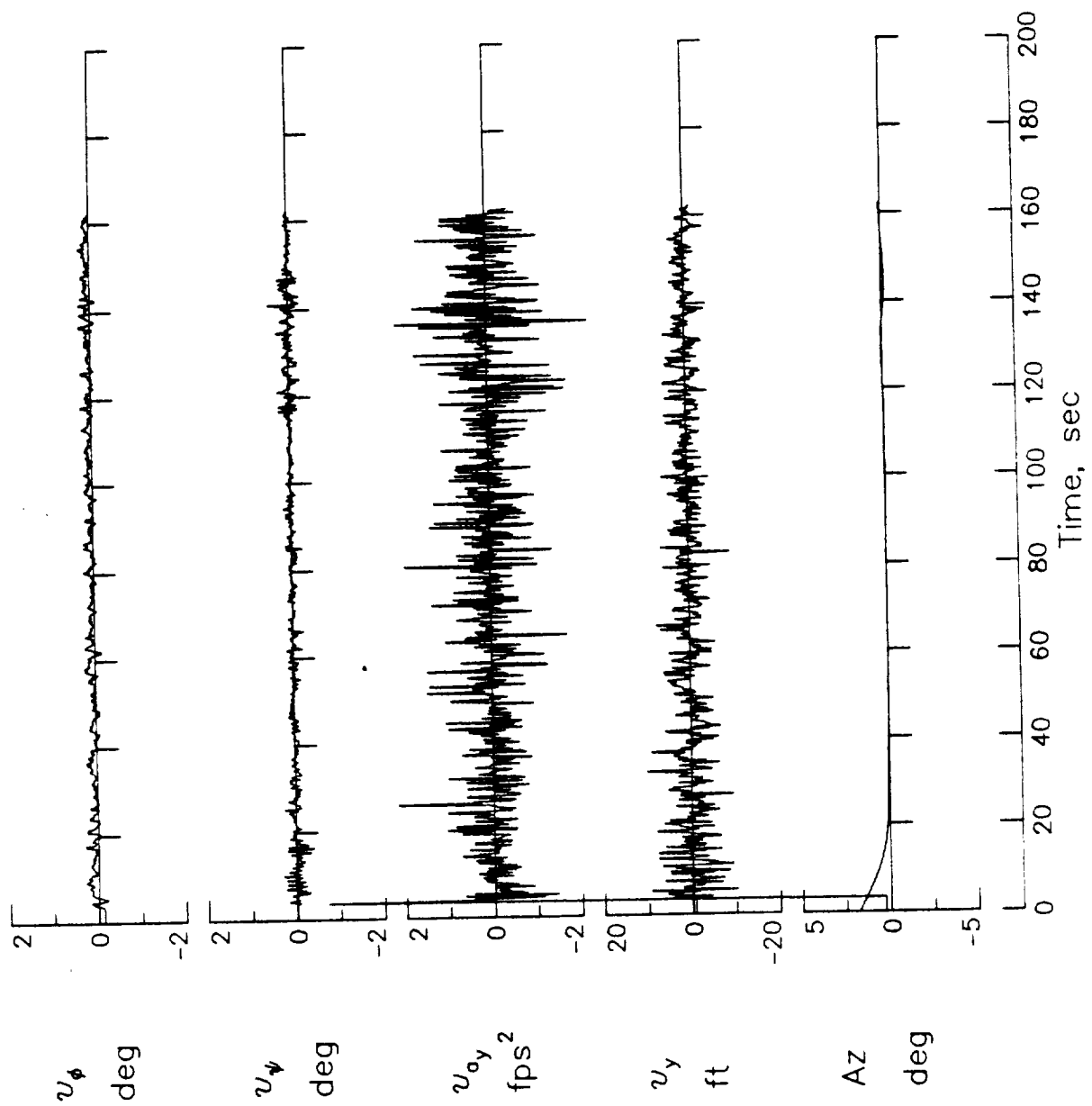


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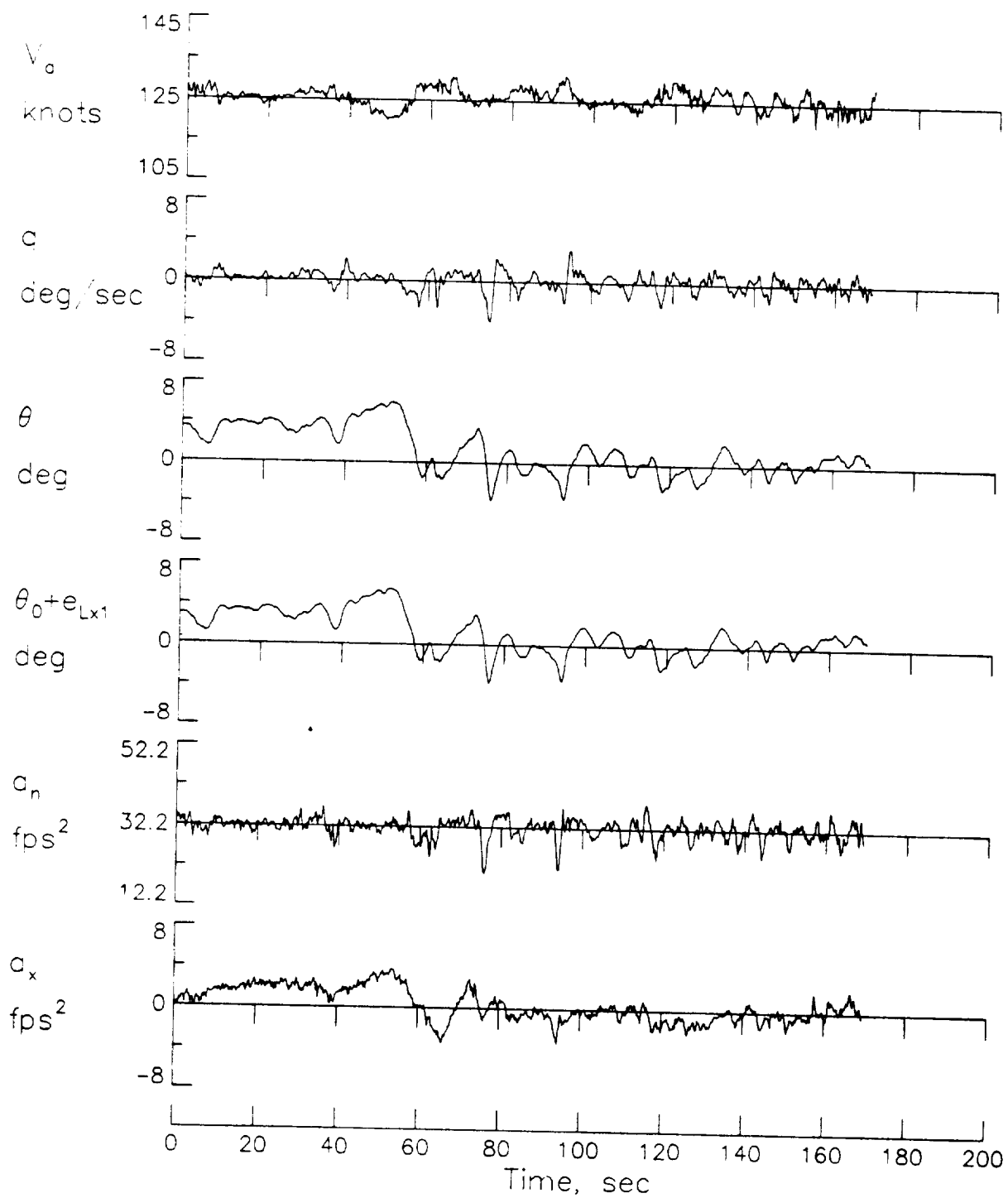


Figure 4. Flight Test Data for DIALS Flight Test R353, Run 6R3

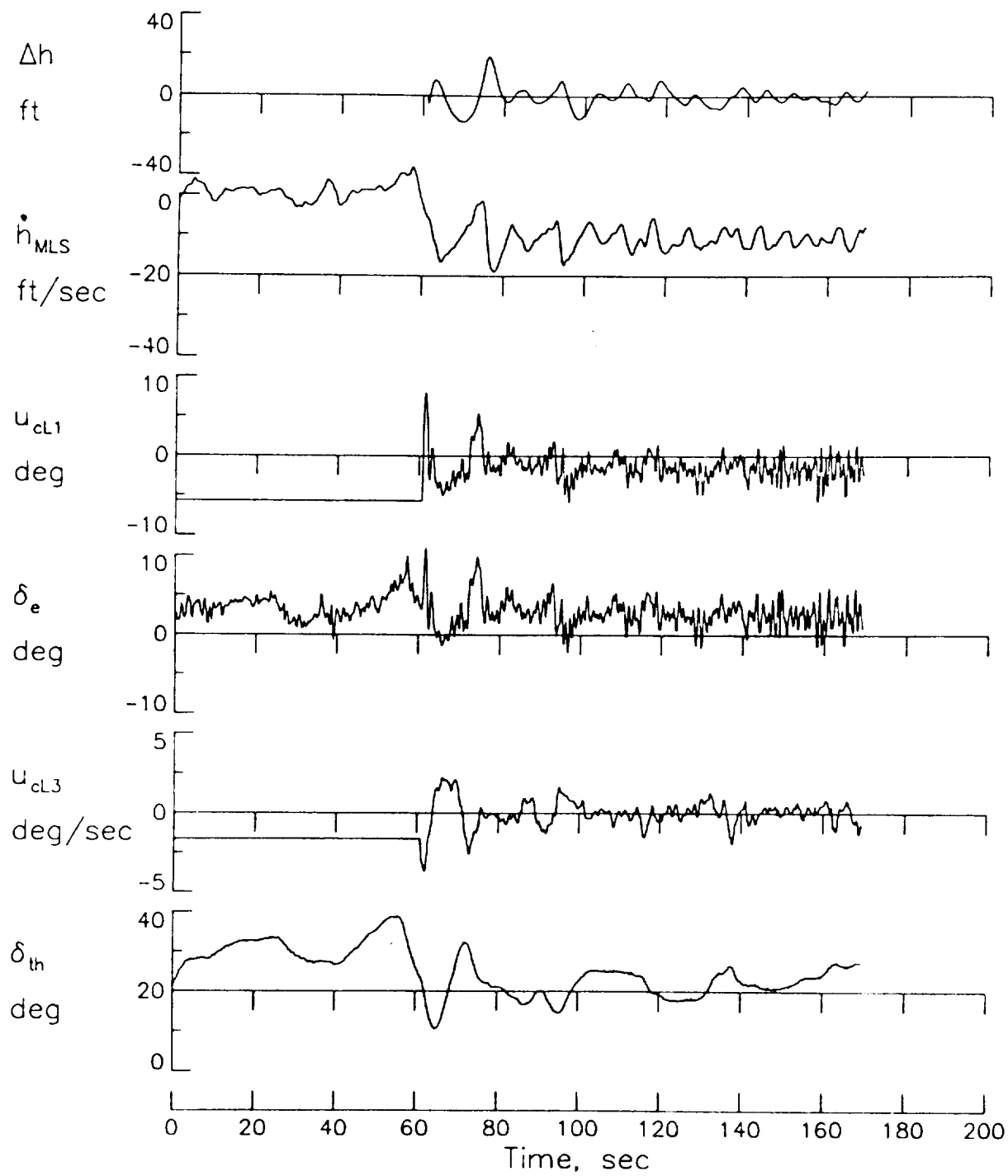


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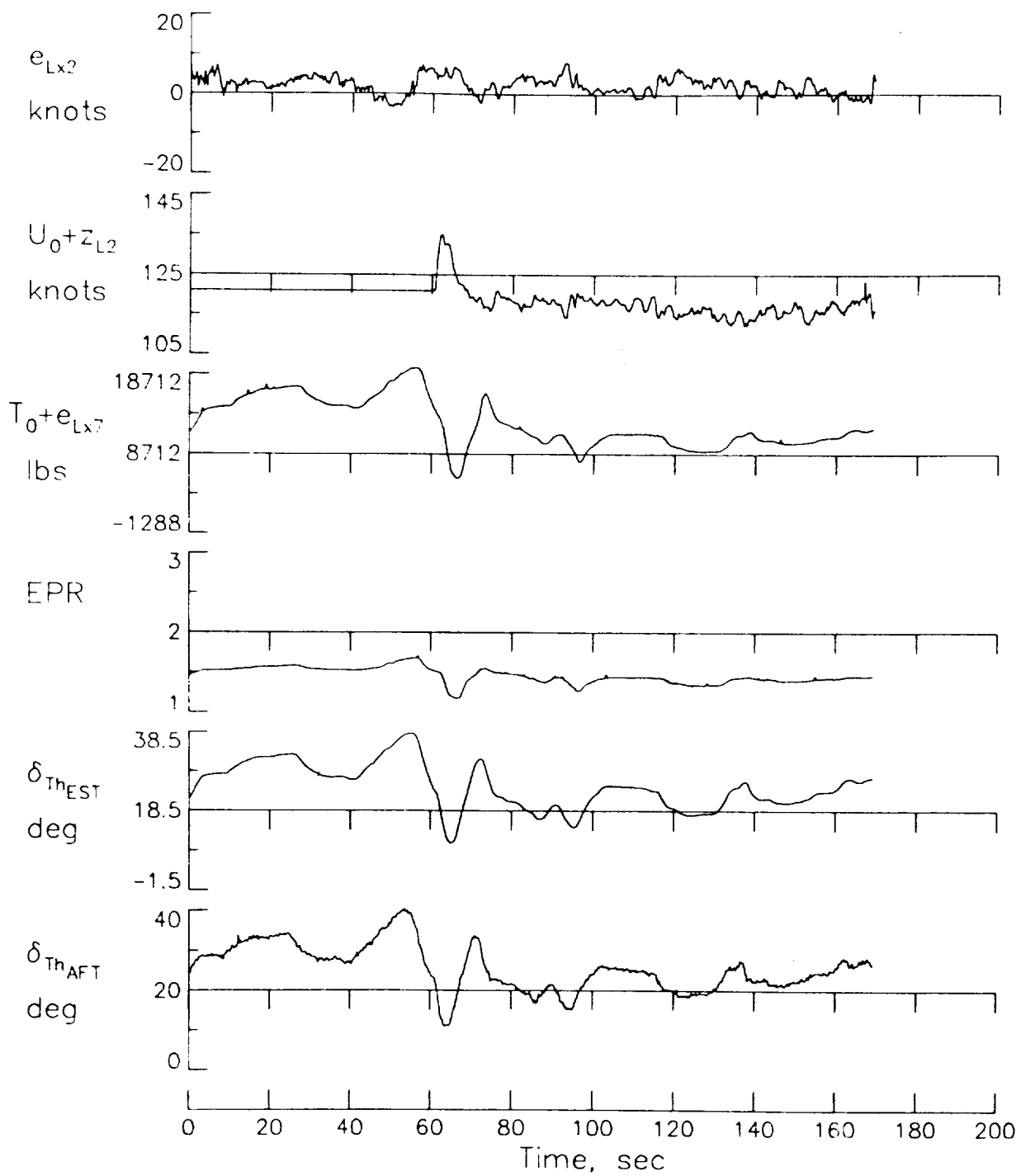


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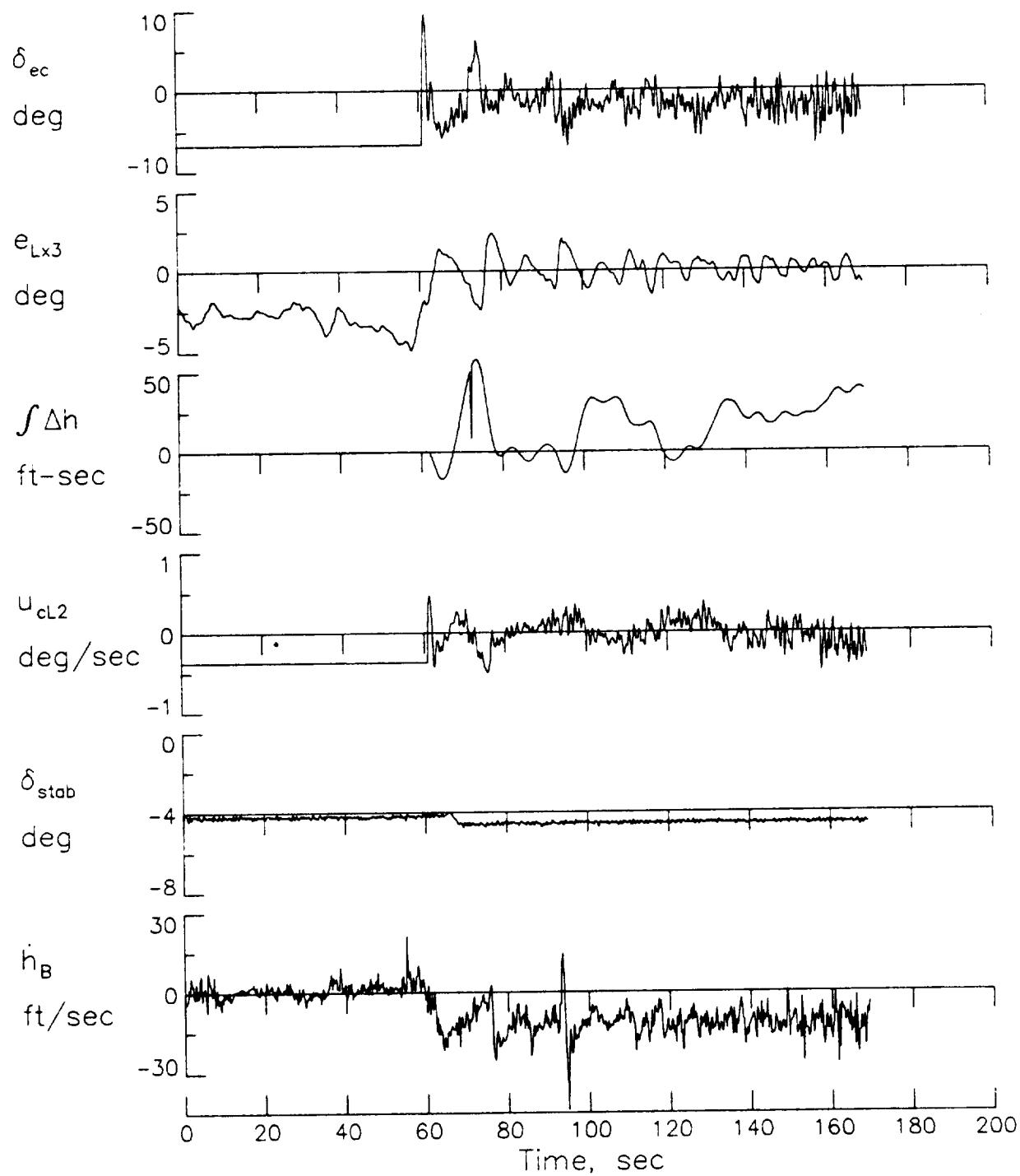


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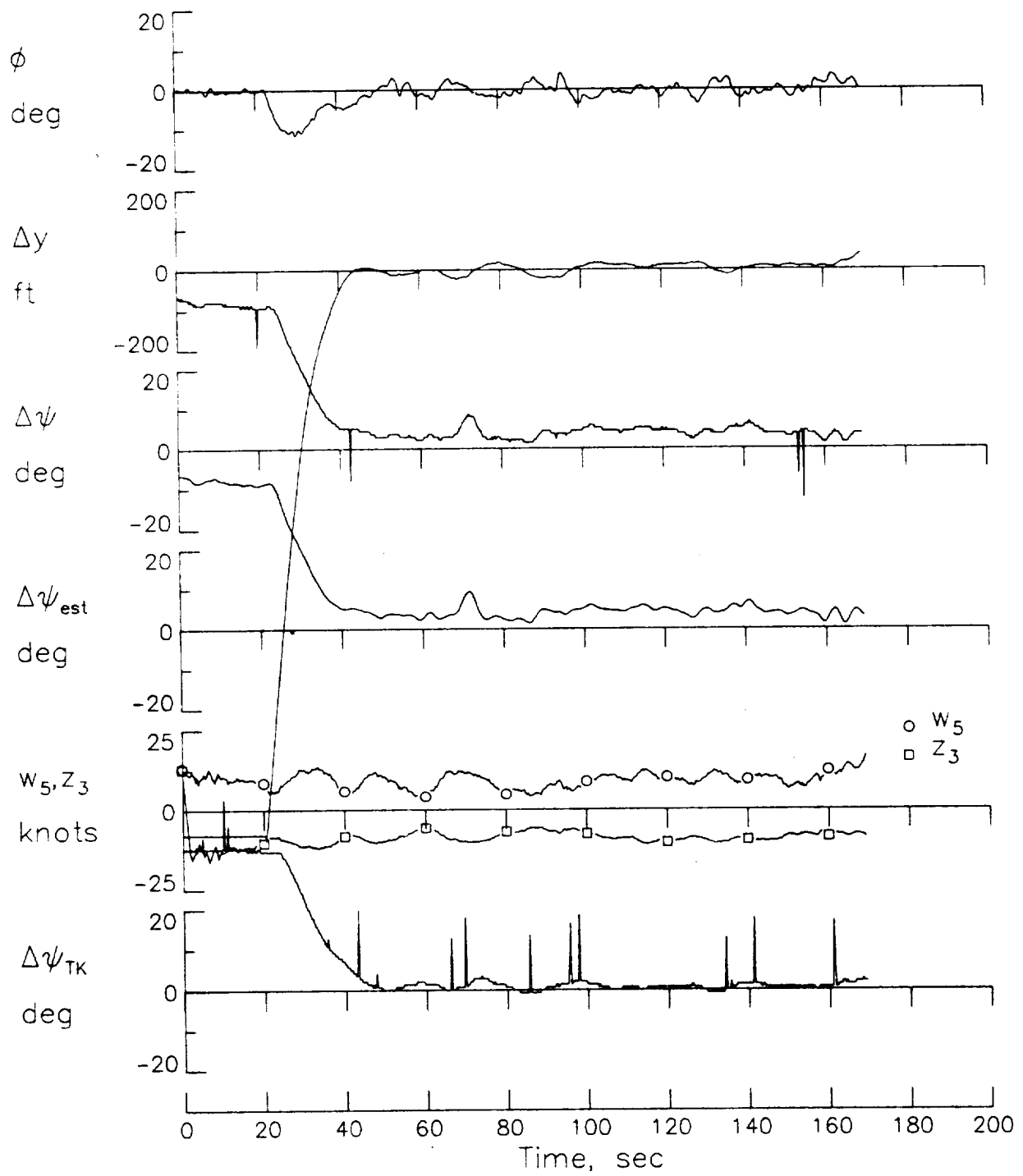


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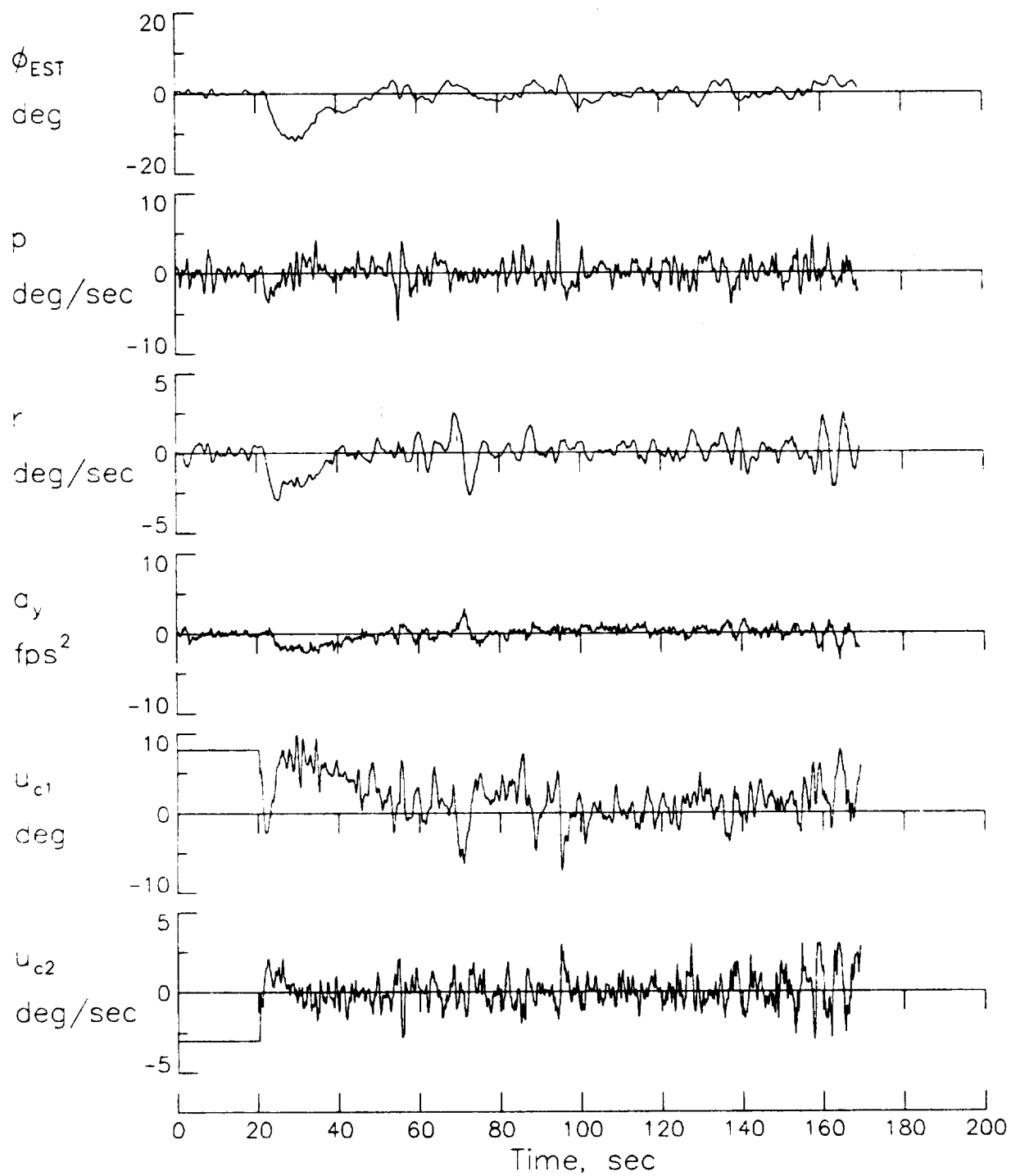


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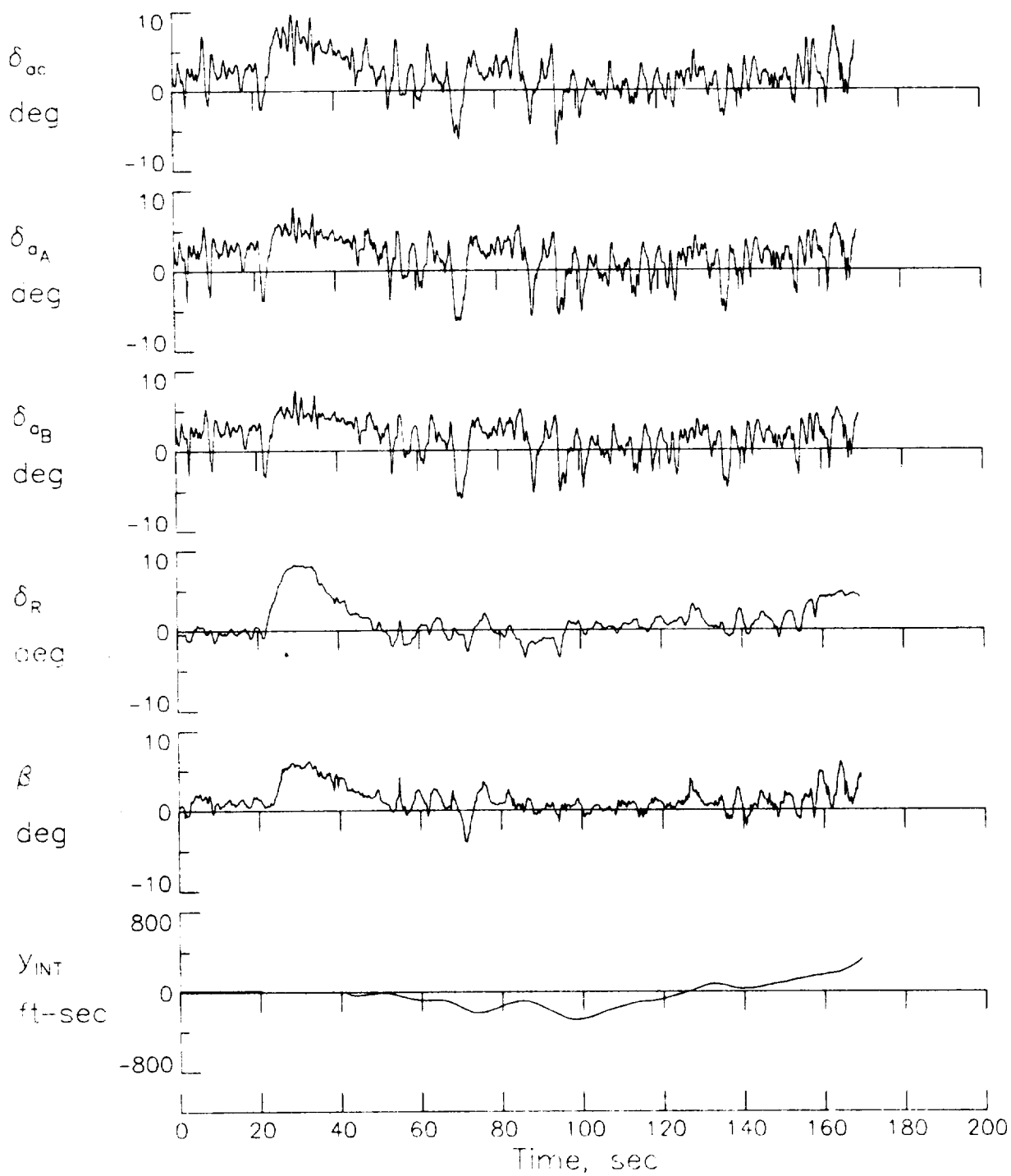


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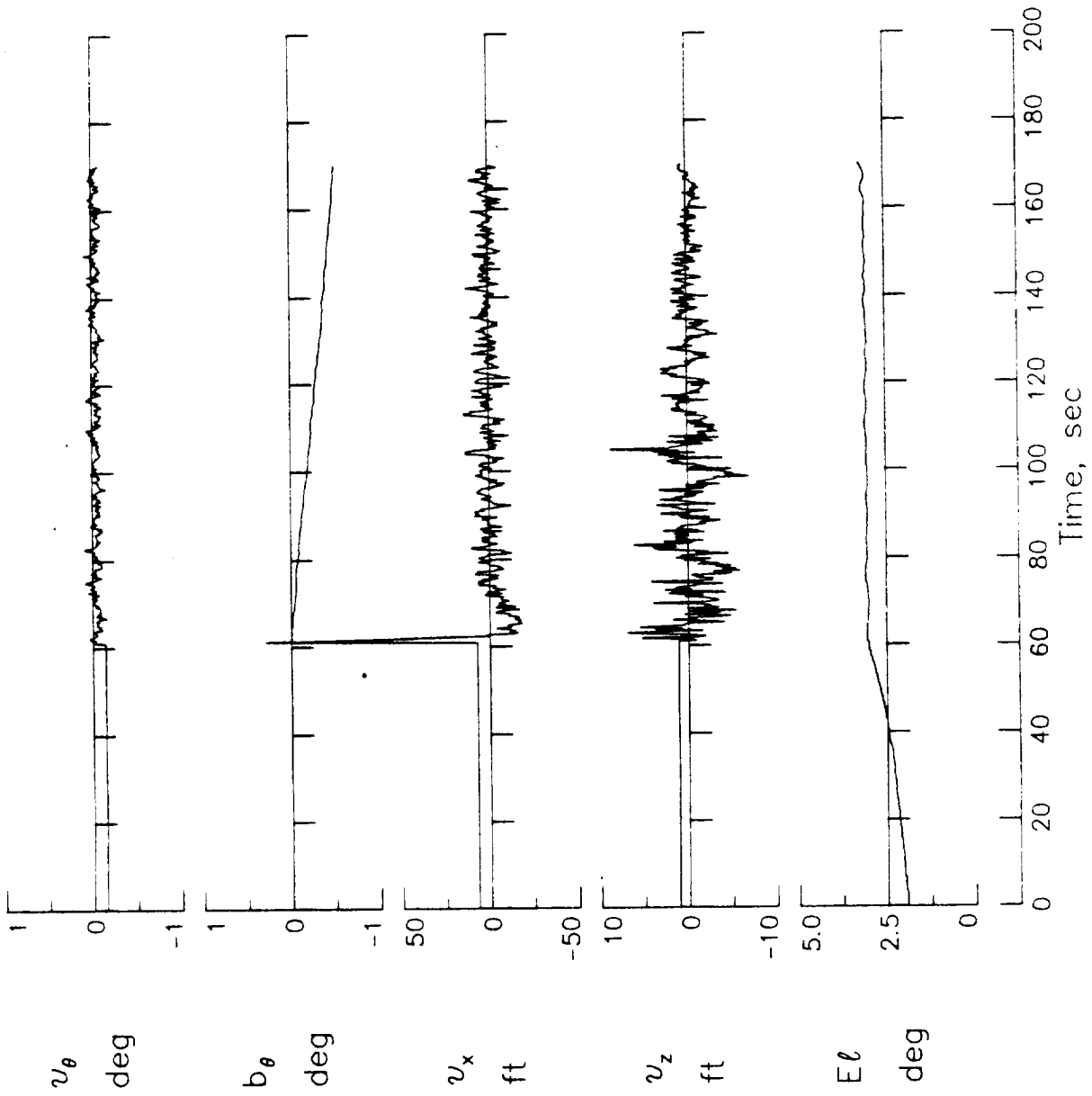


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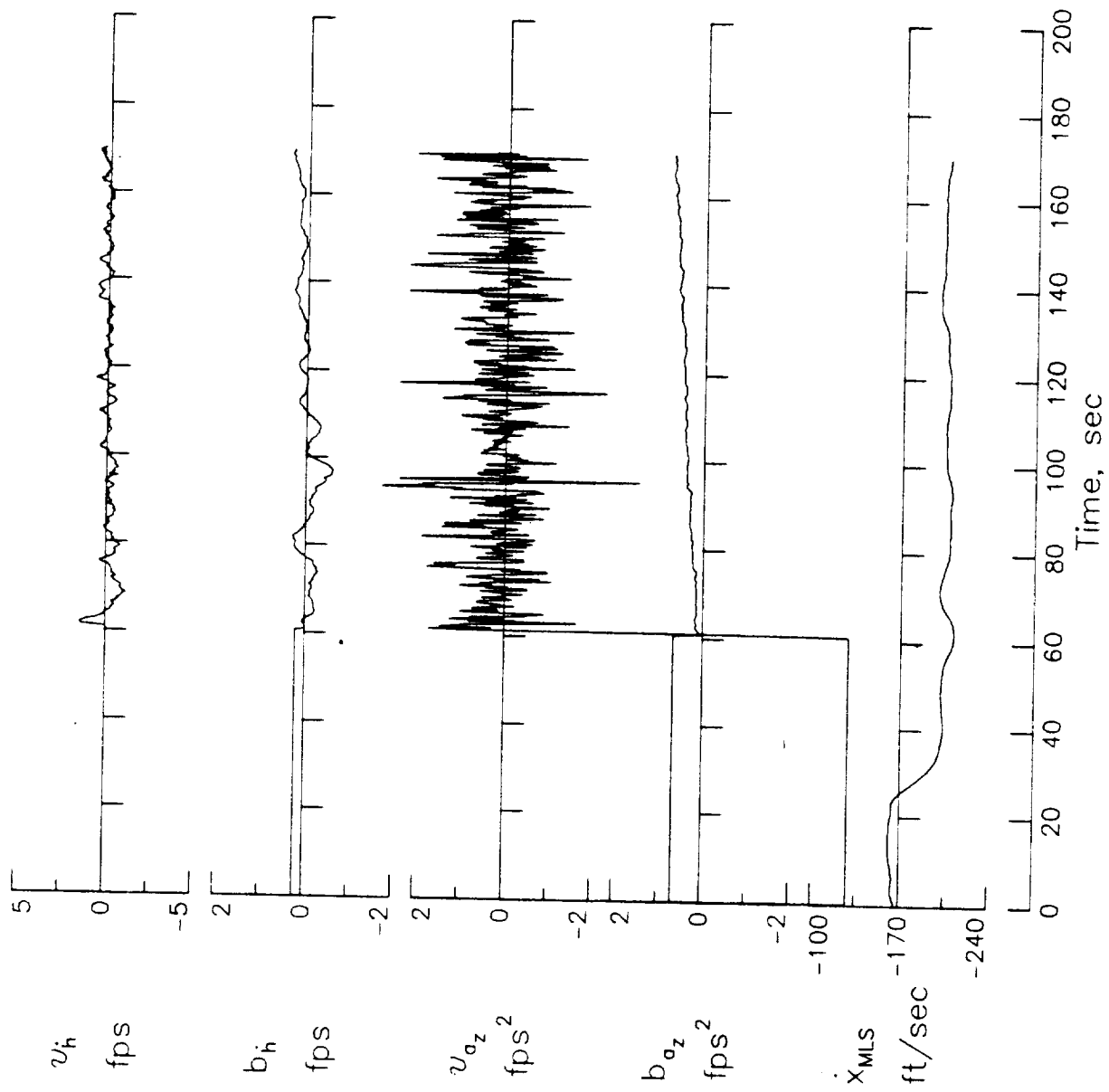


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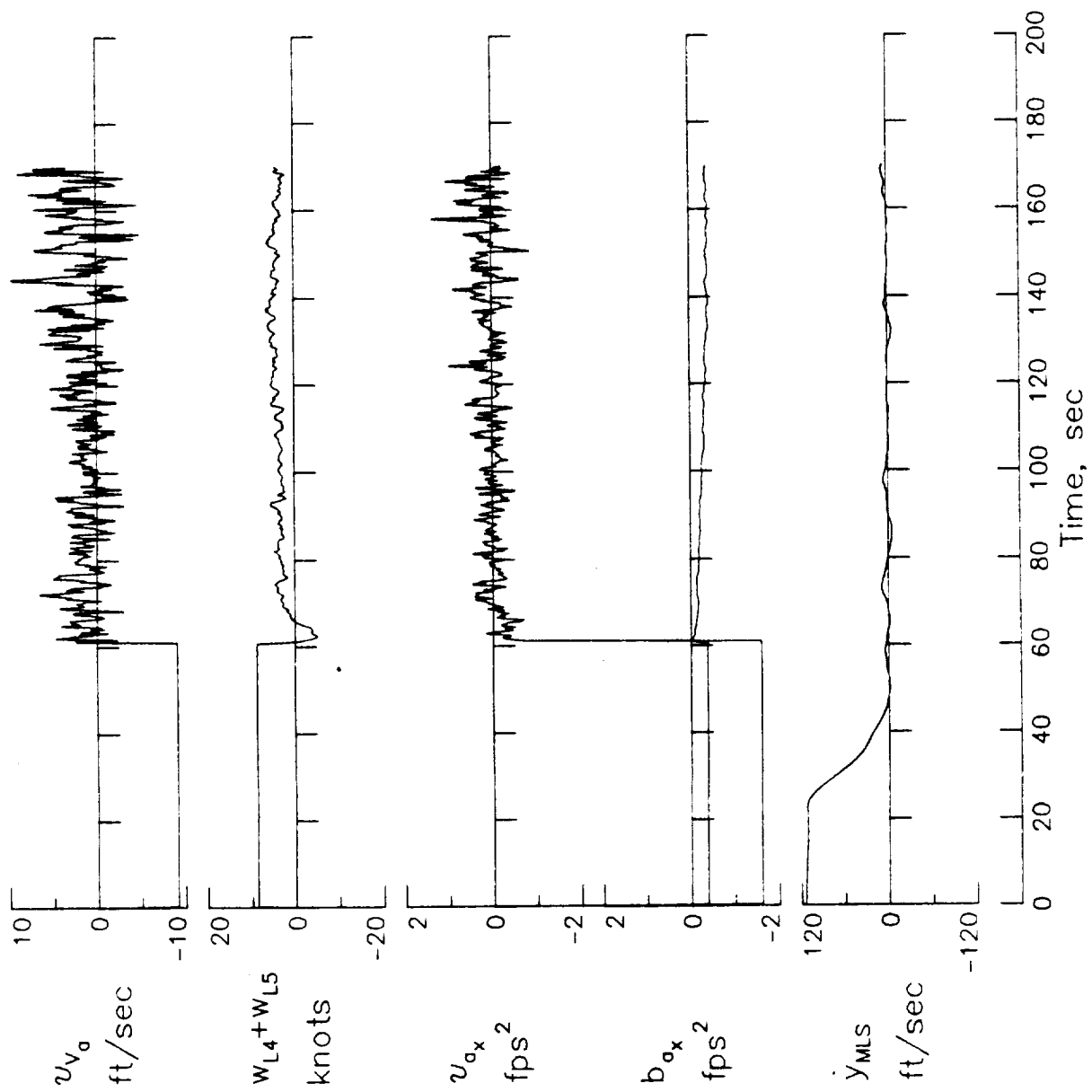


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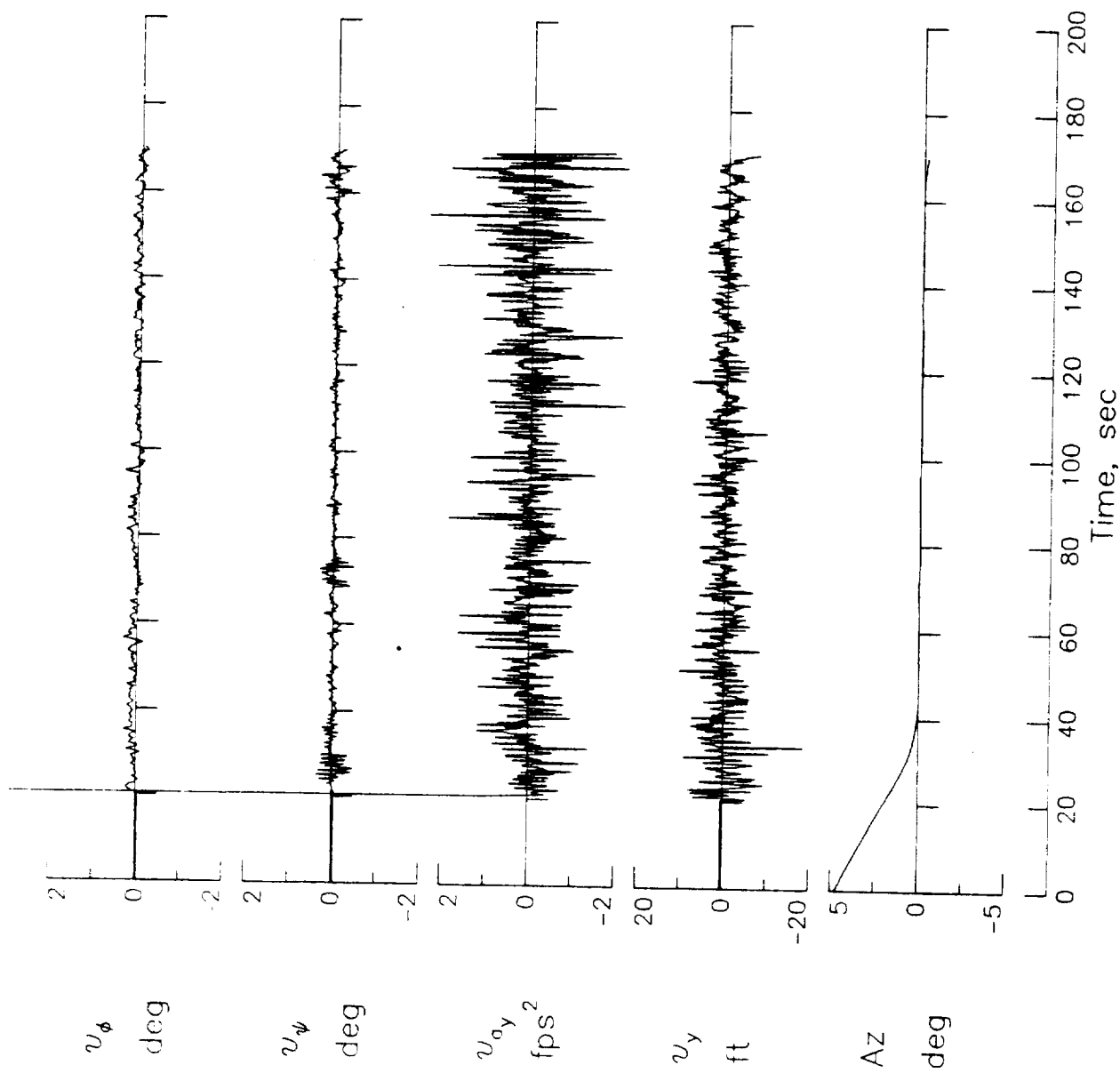


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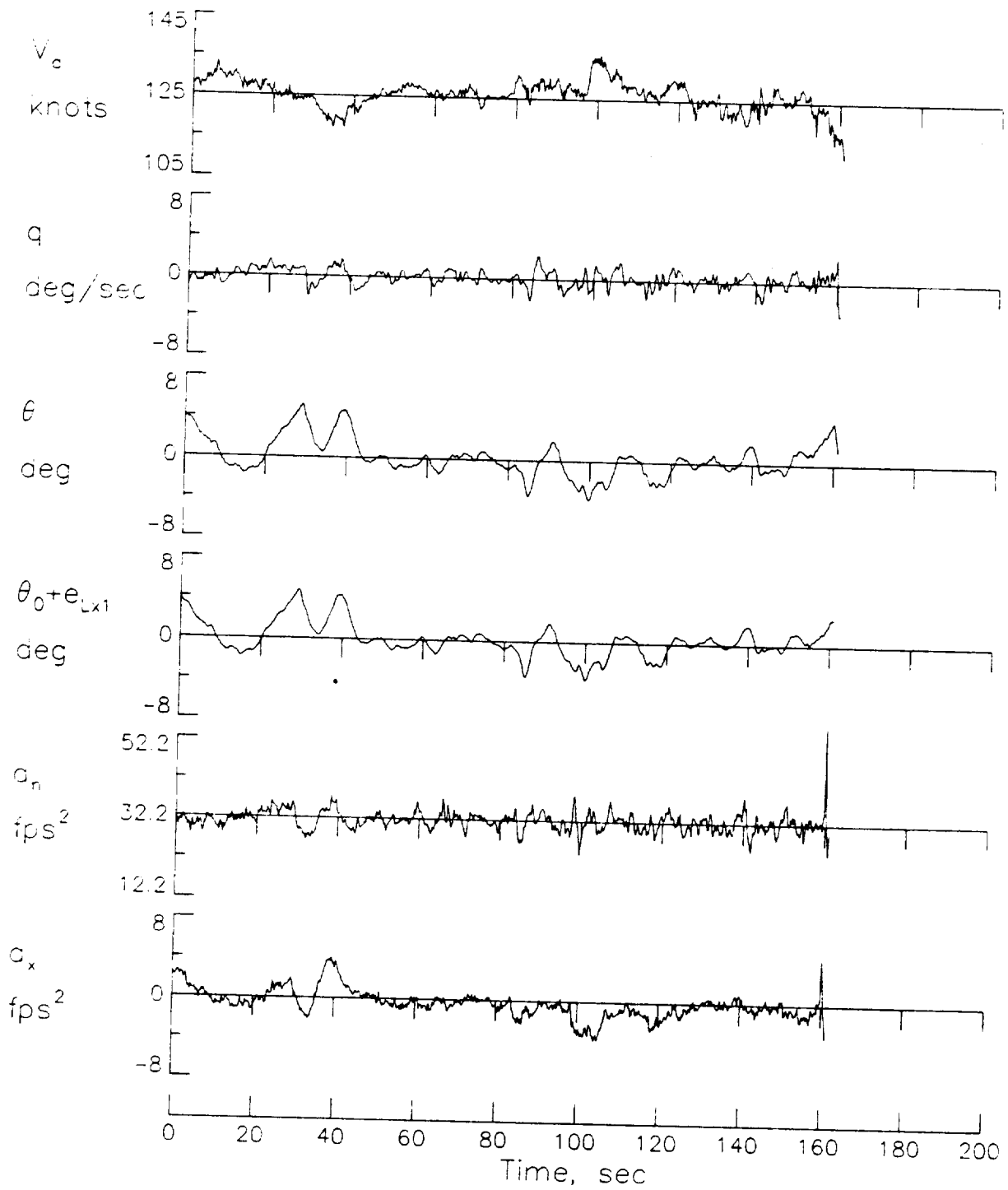


Figure 5. Flight Test Data for DIALS Flight Test
R353, Run 6R4

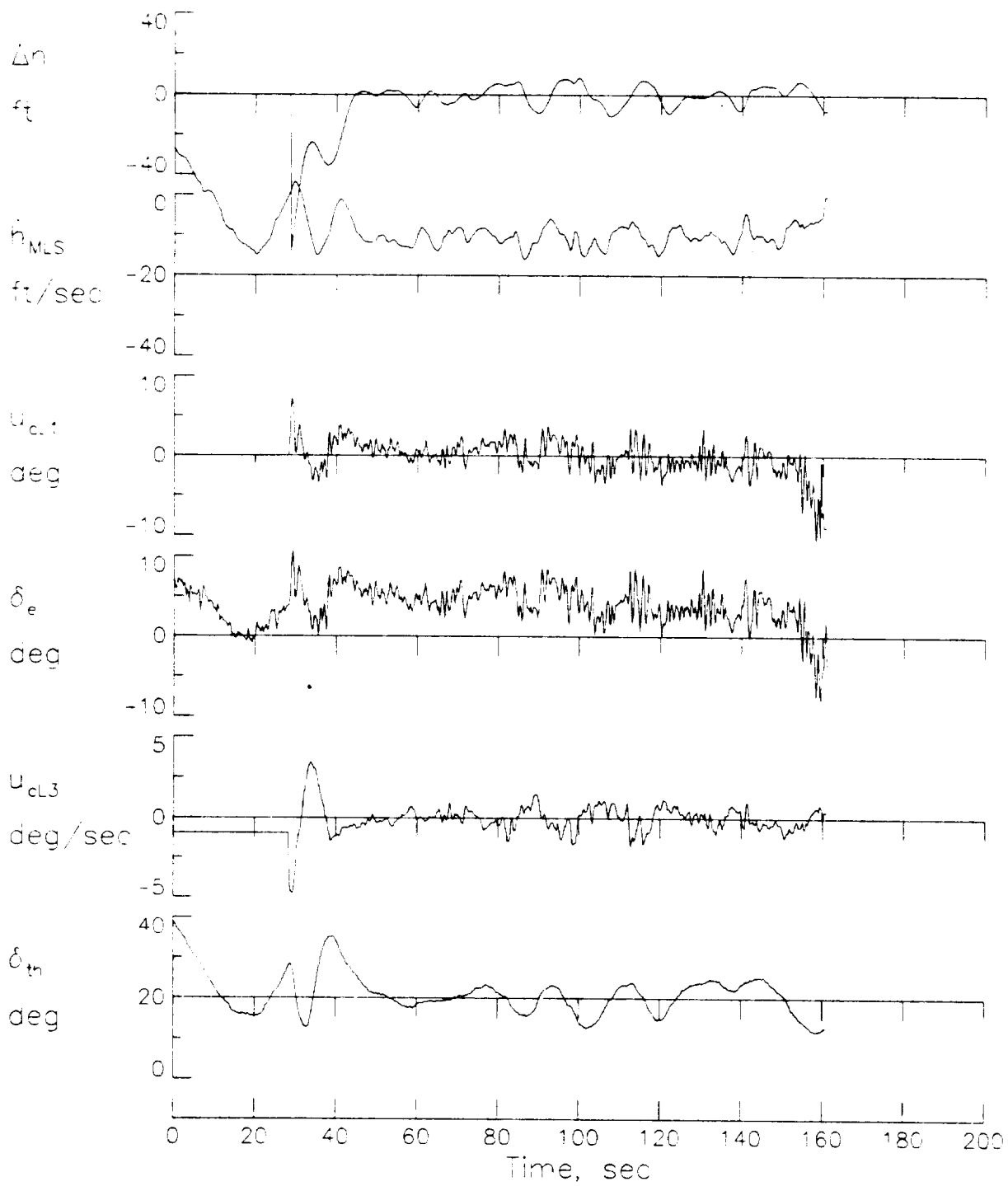


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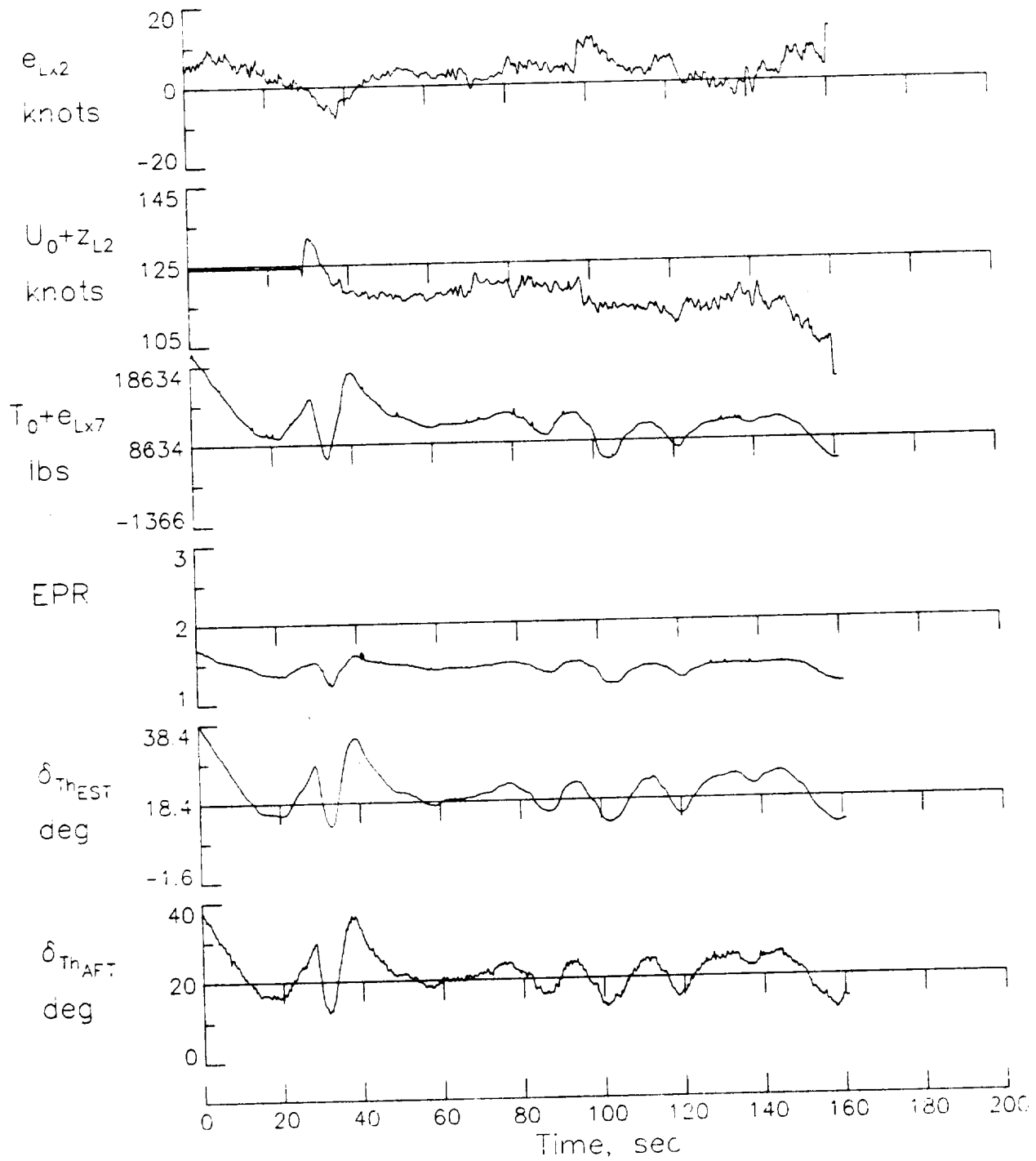


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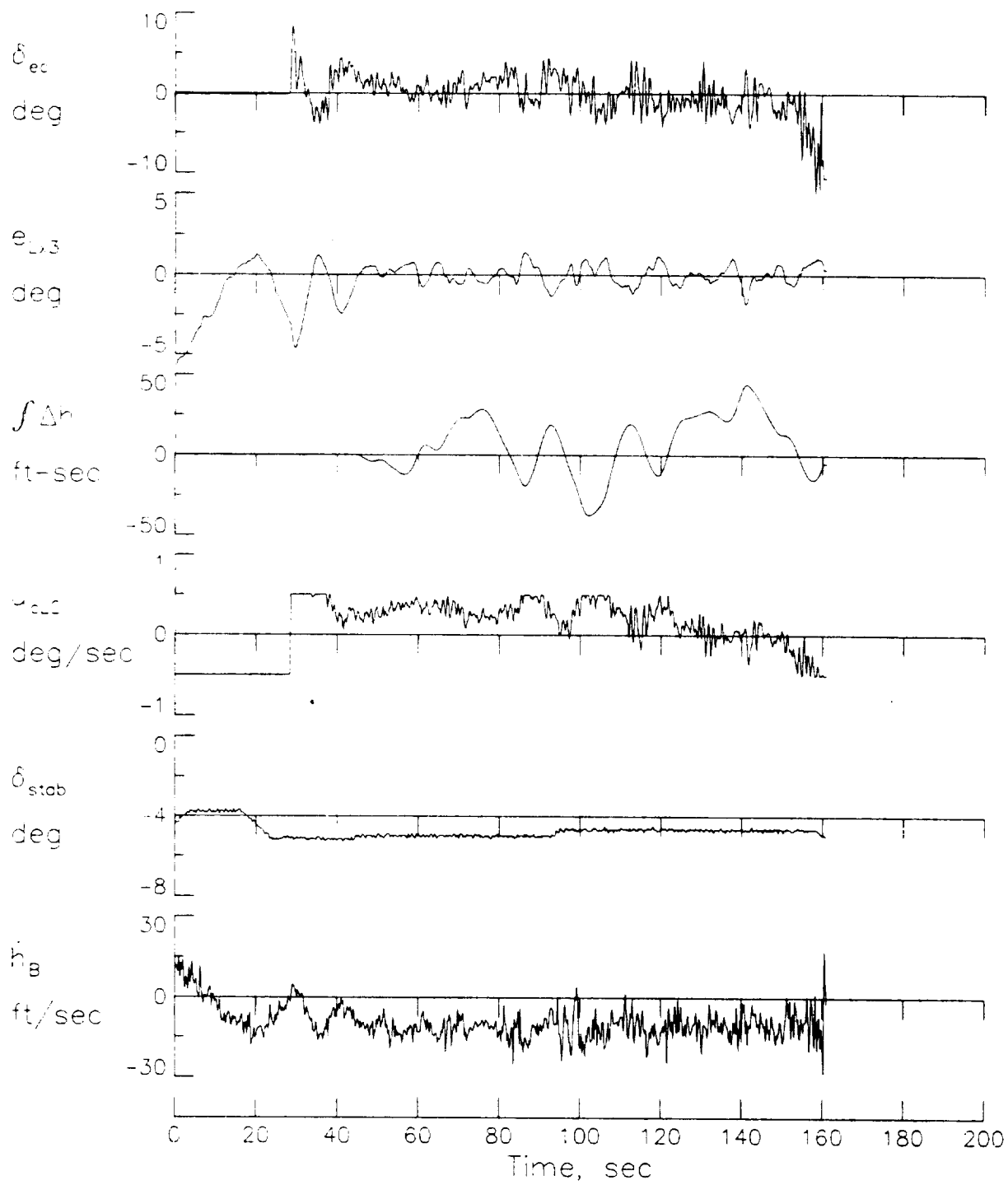


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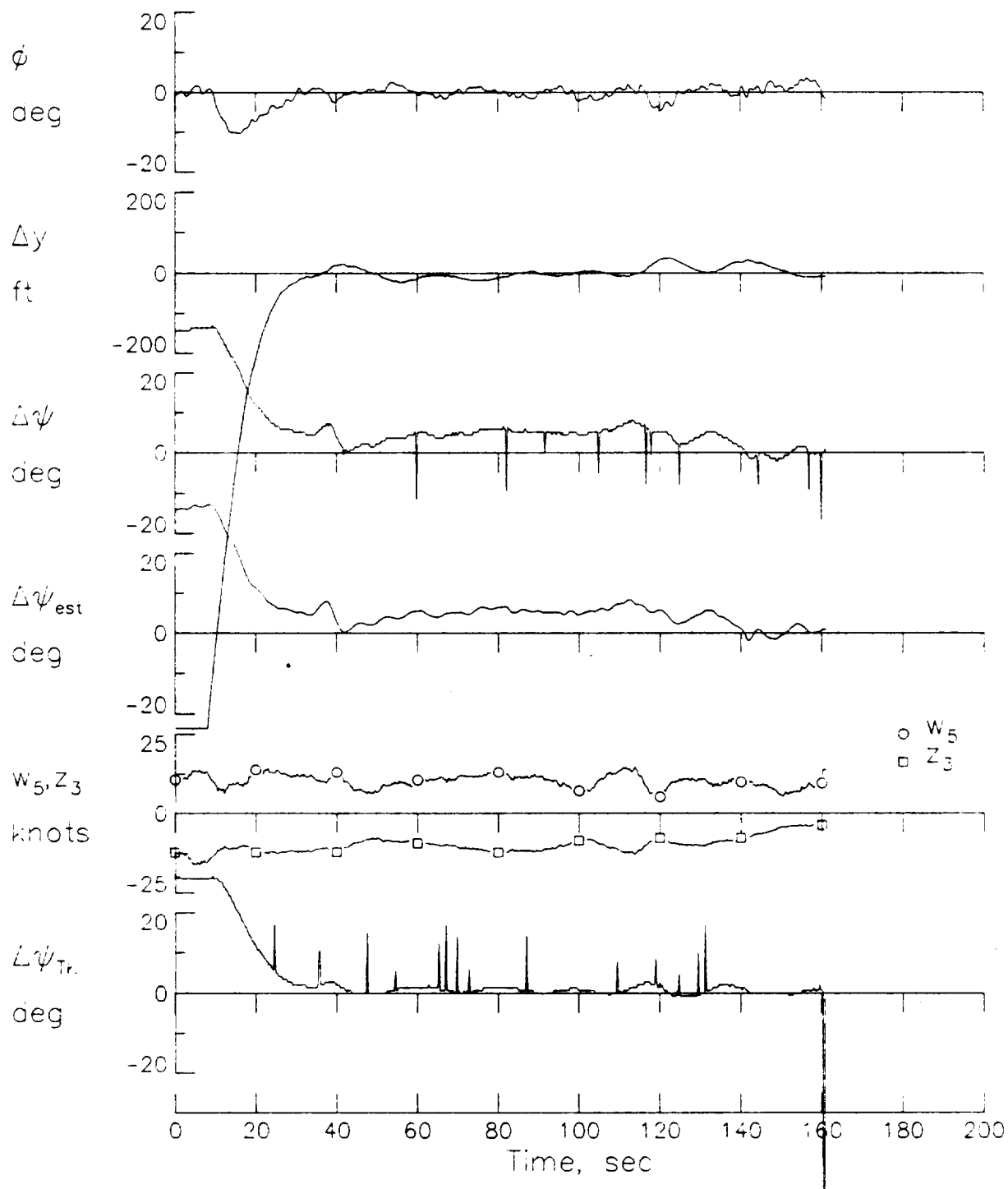


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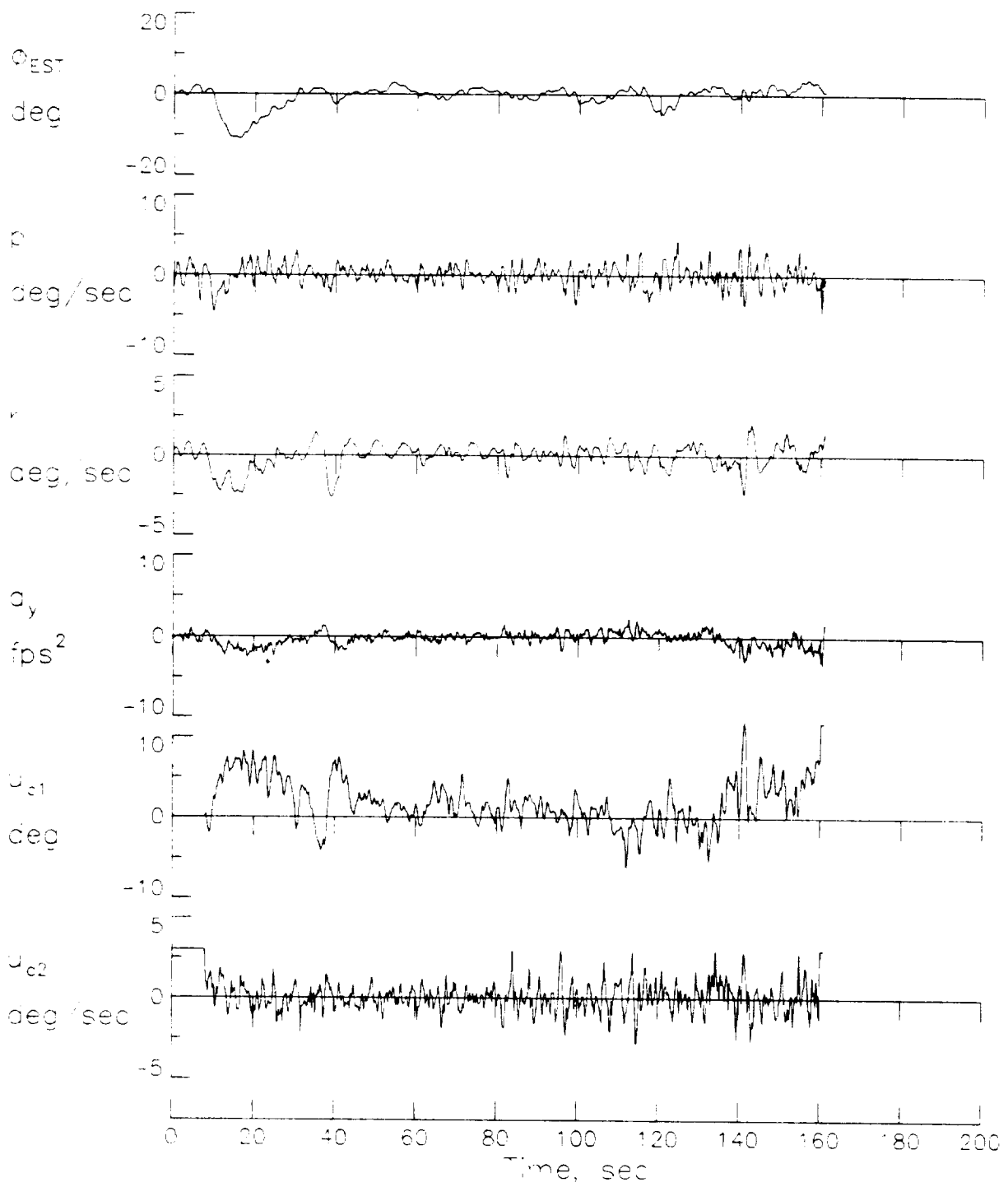


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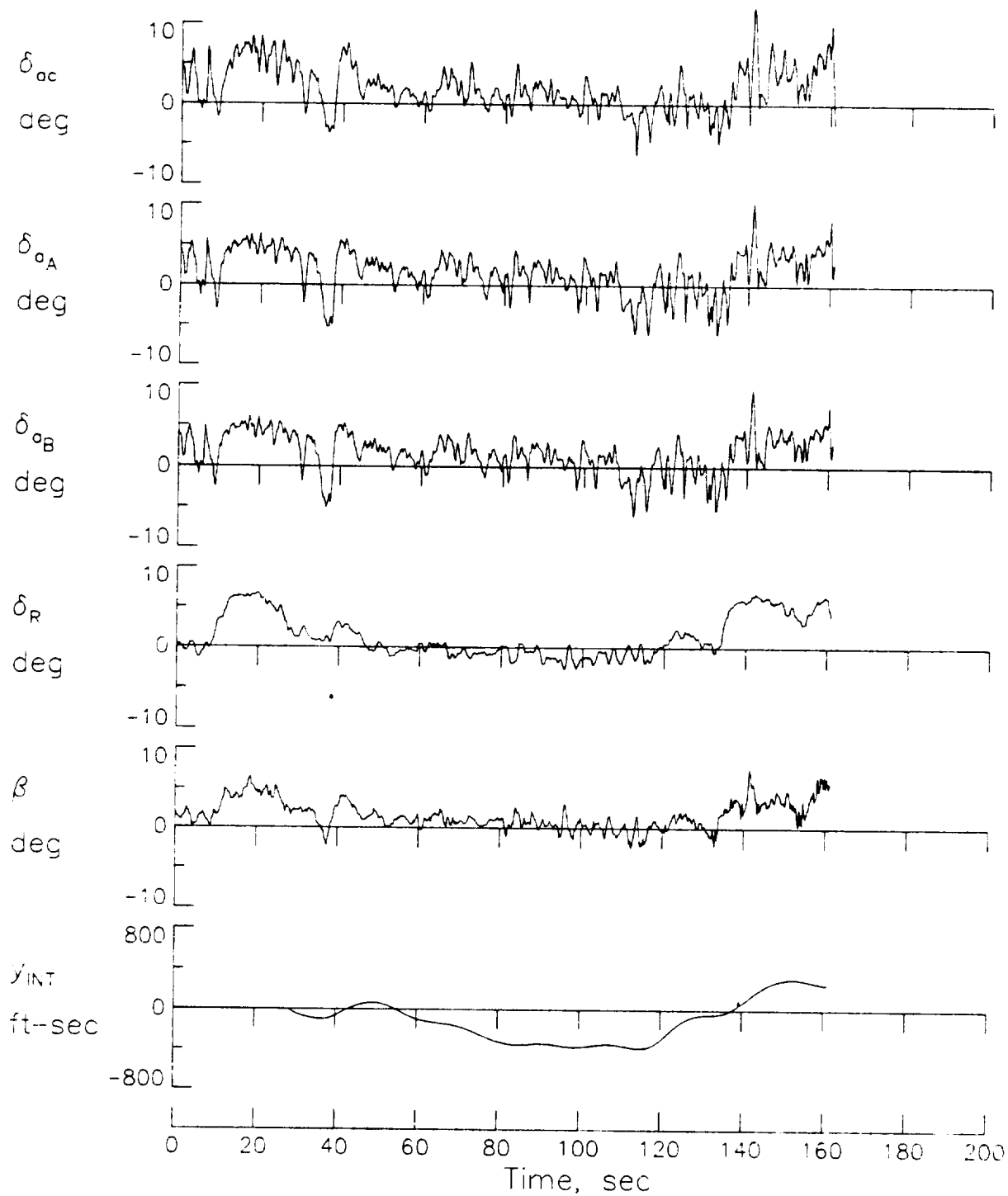


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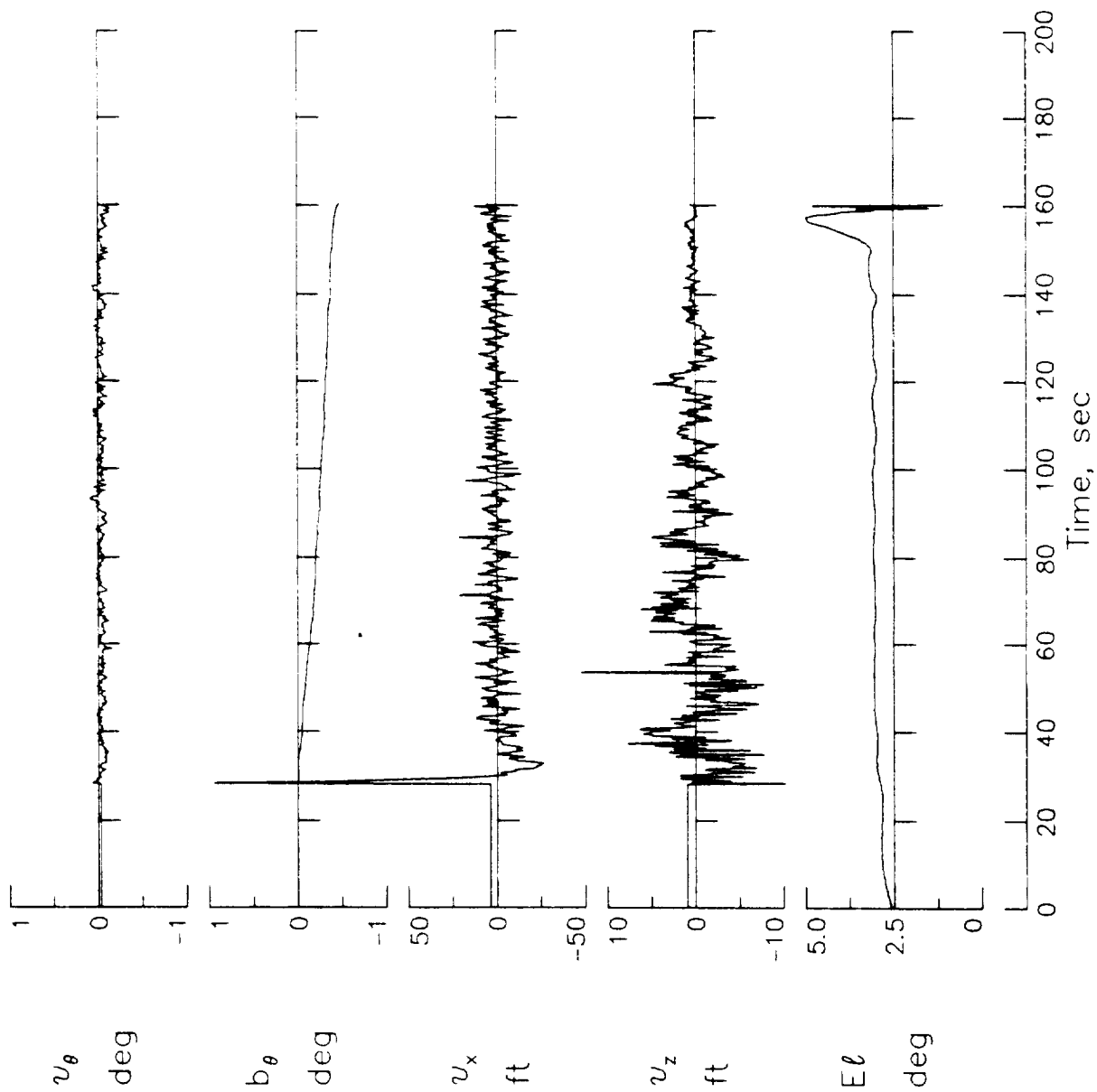


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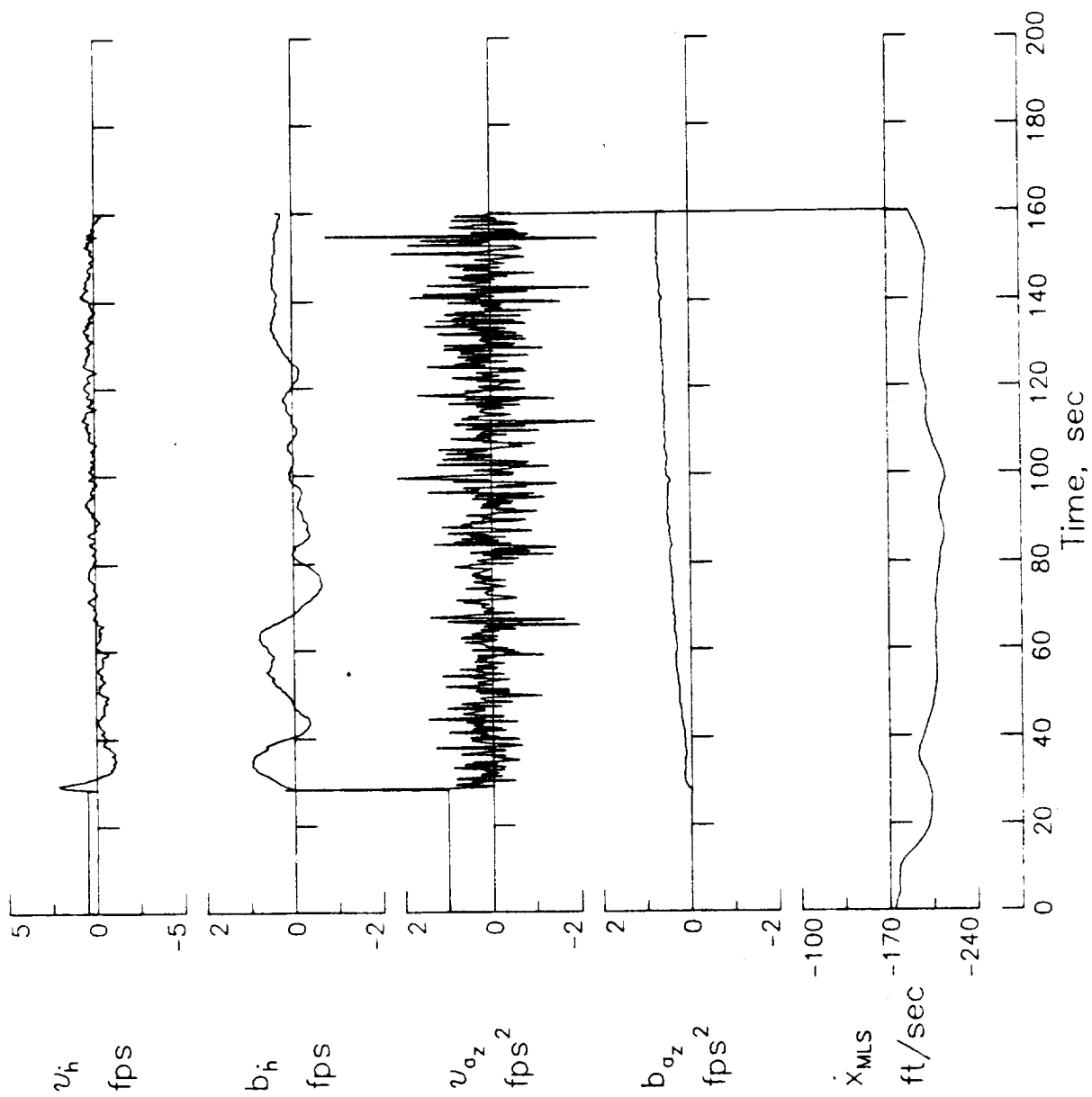


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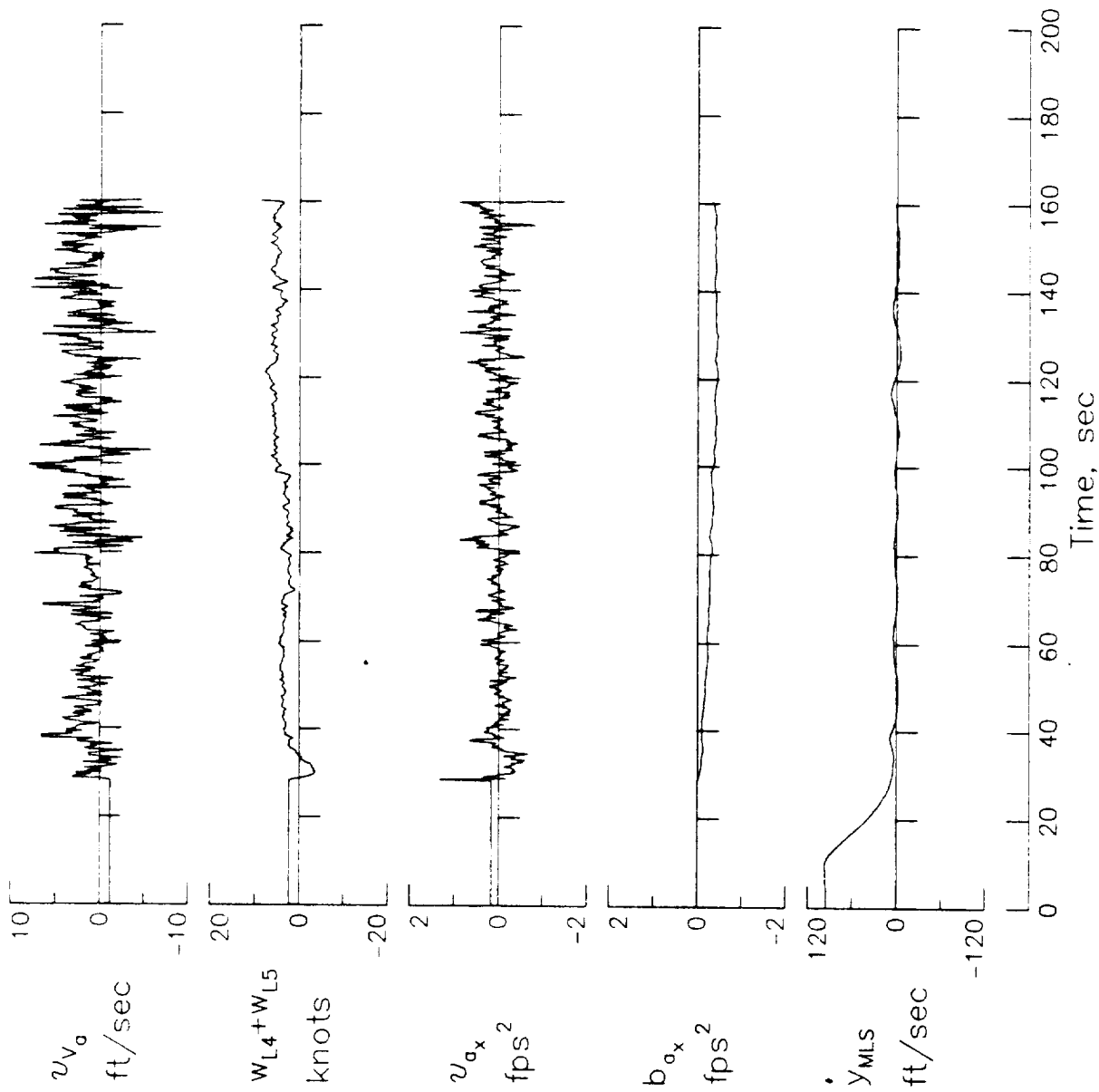


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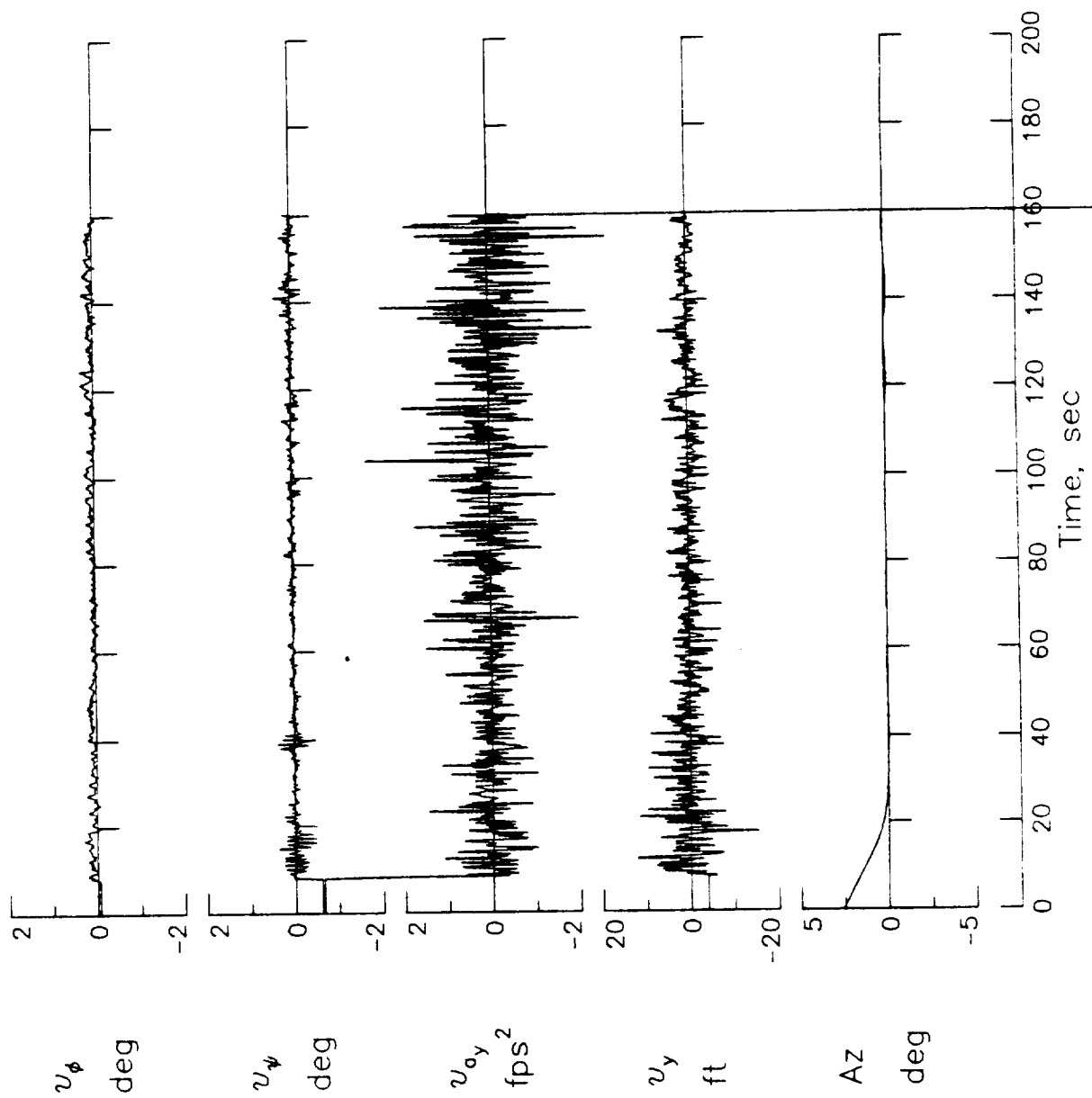


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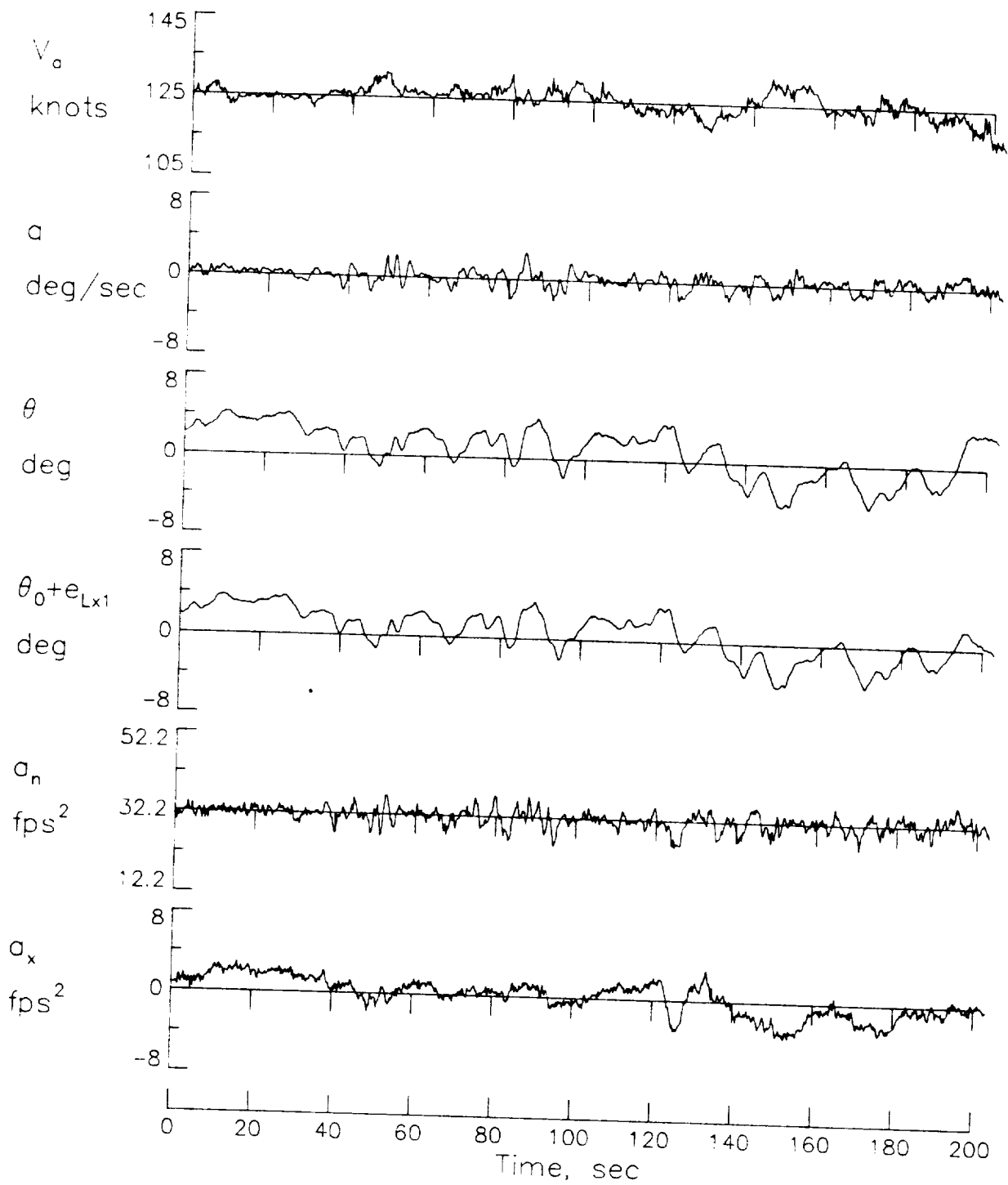


Figure 6. Flight Test Data for DIALS Flight Test R353, Run 7

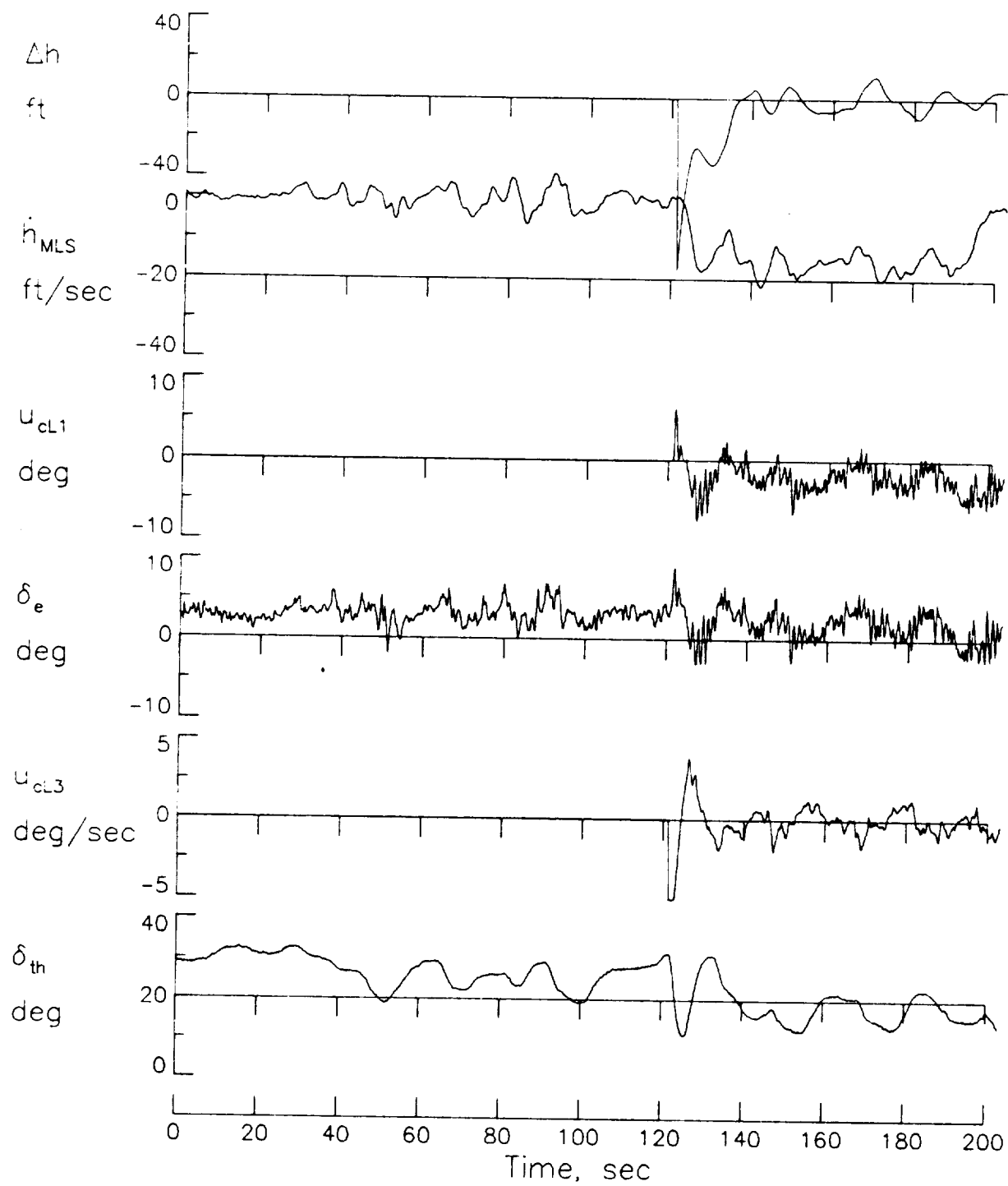


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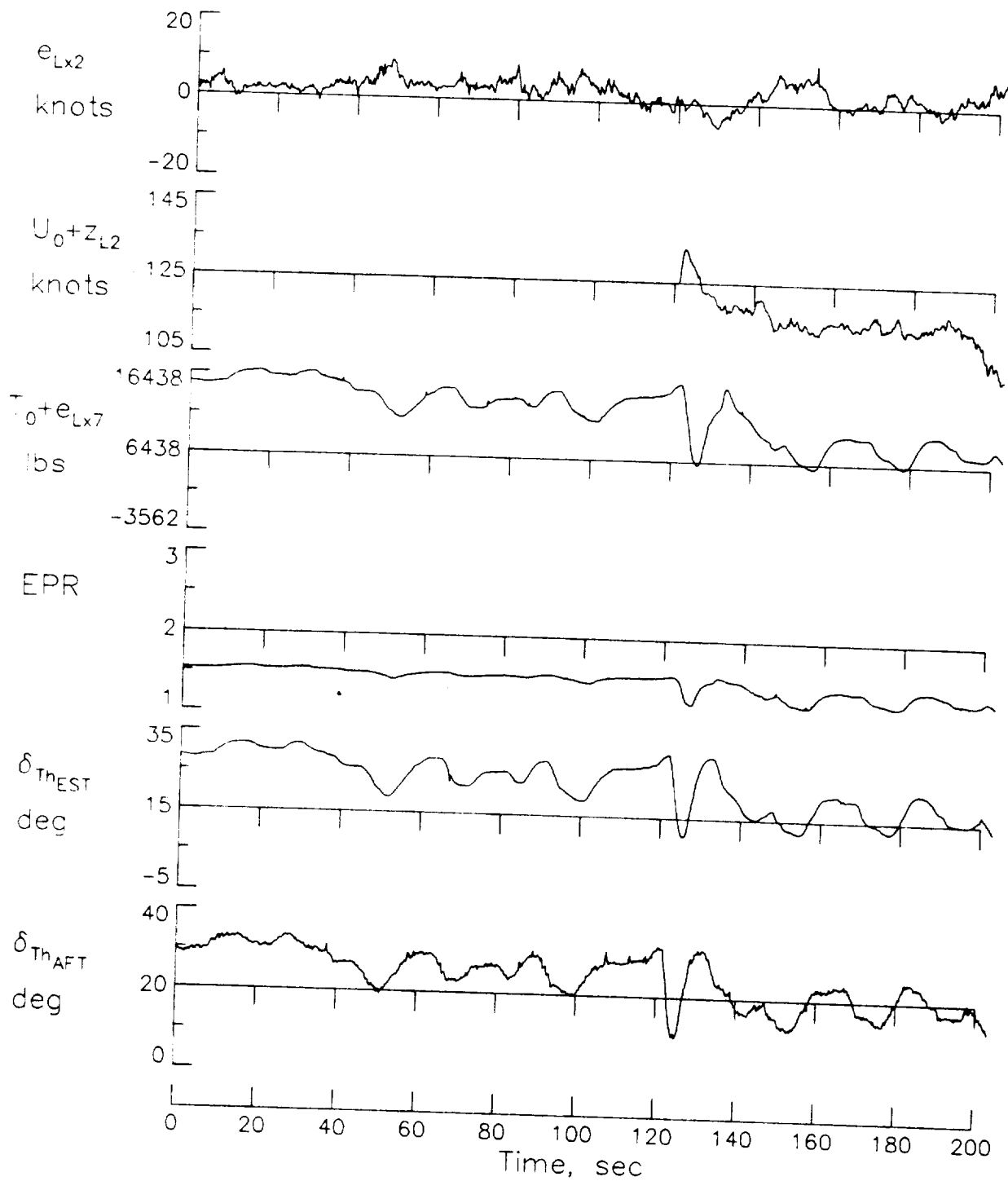


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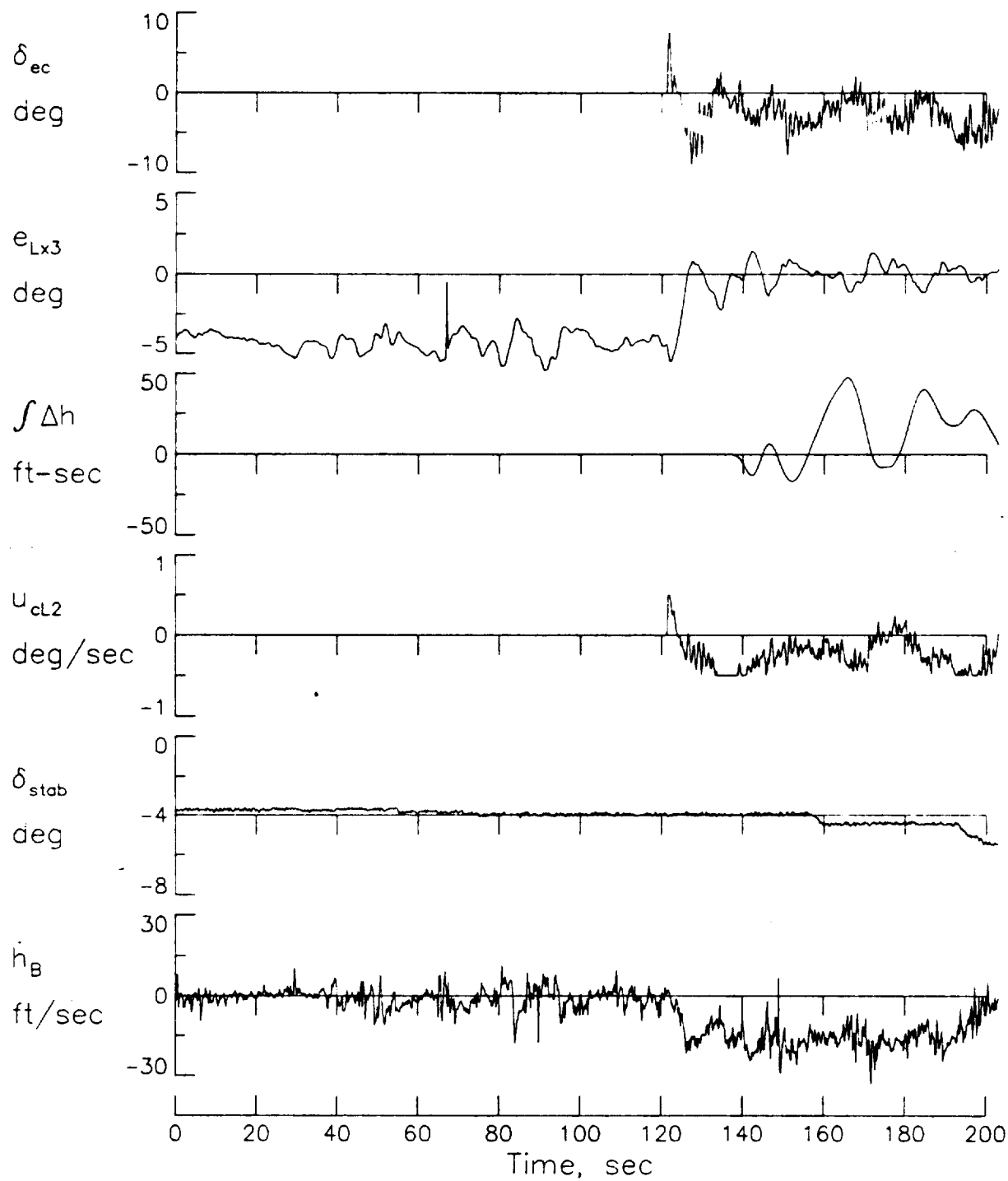


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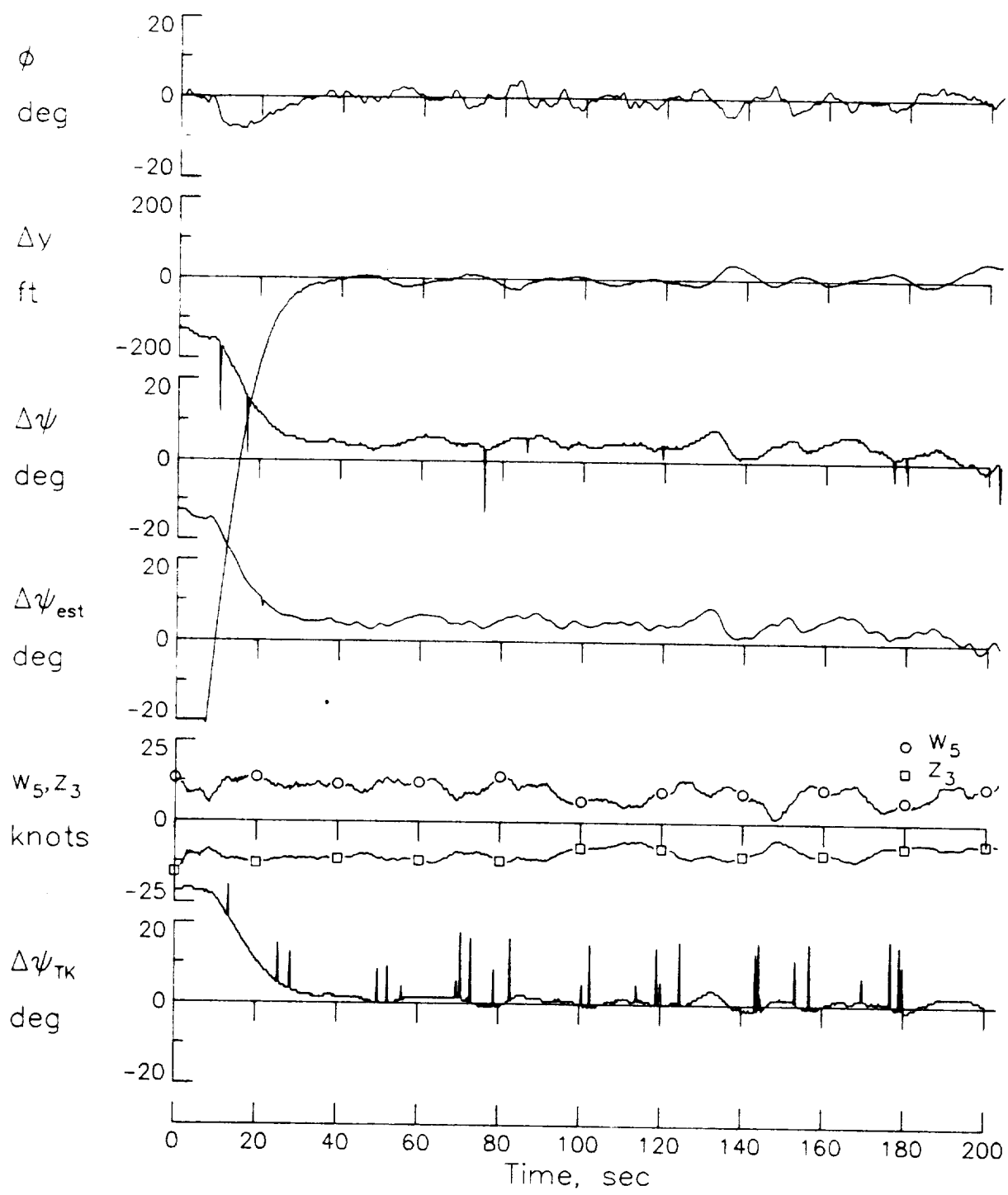


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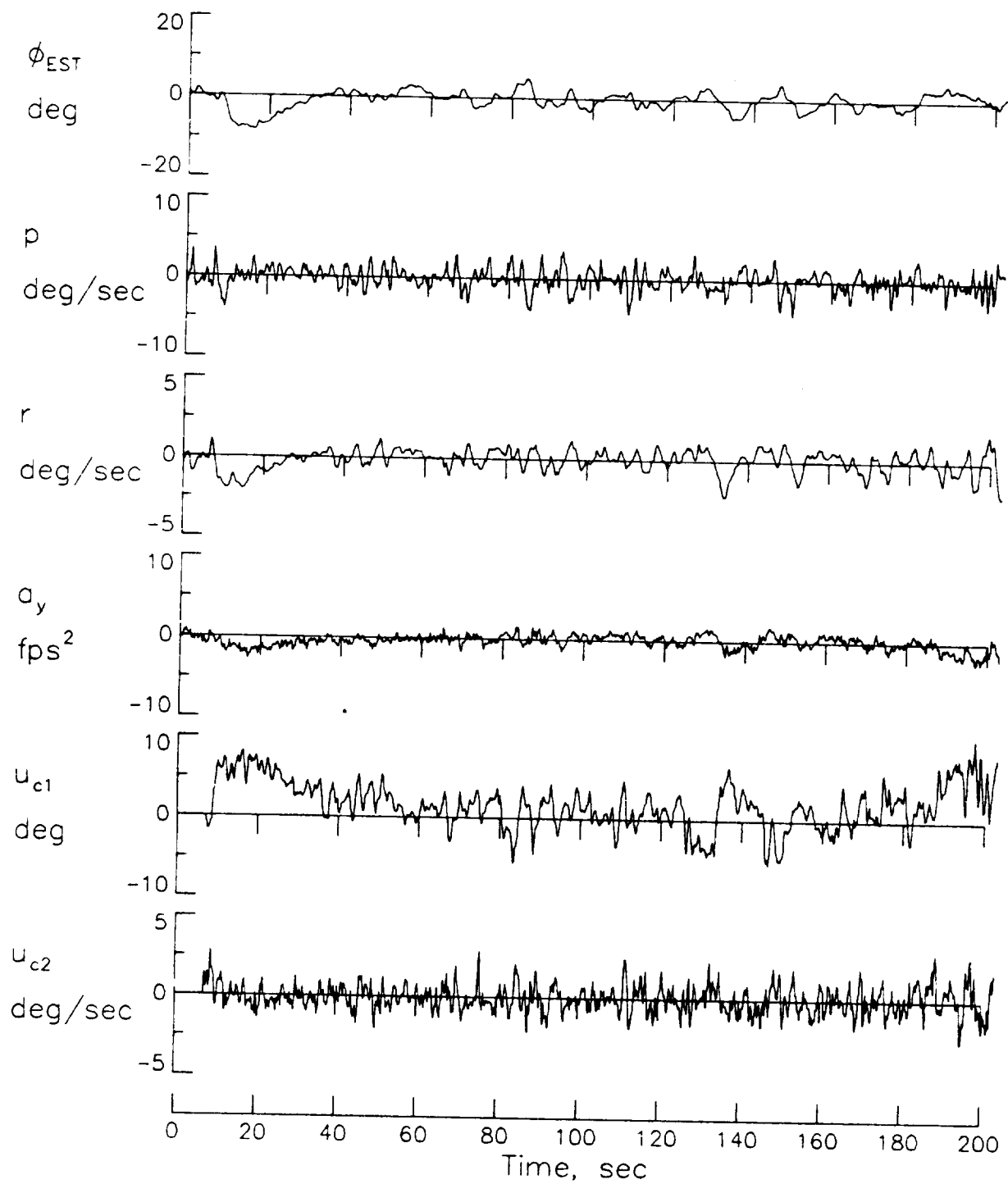


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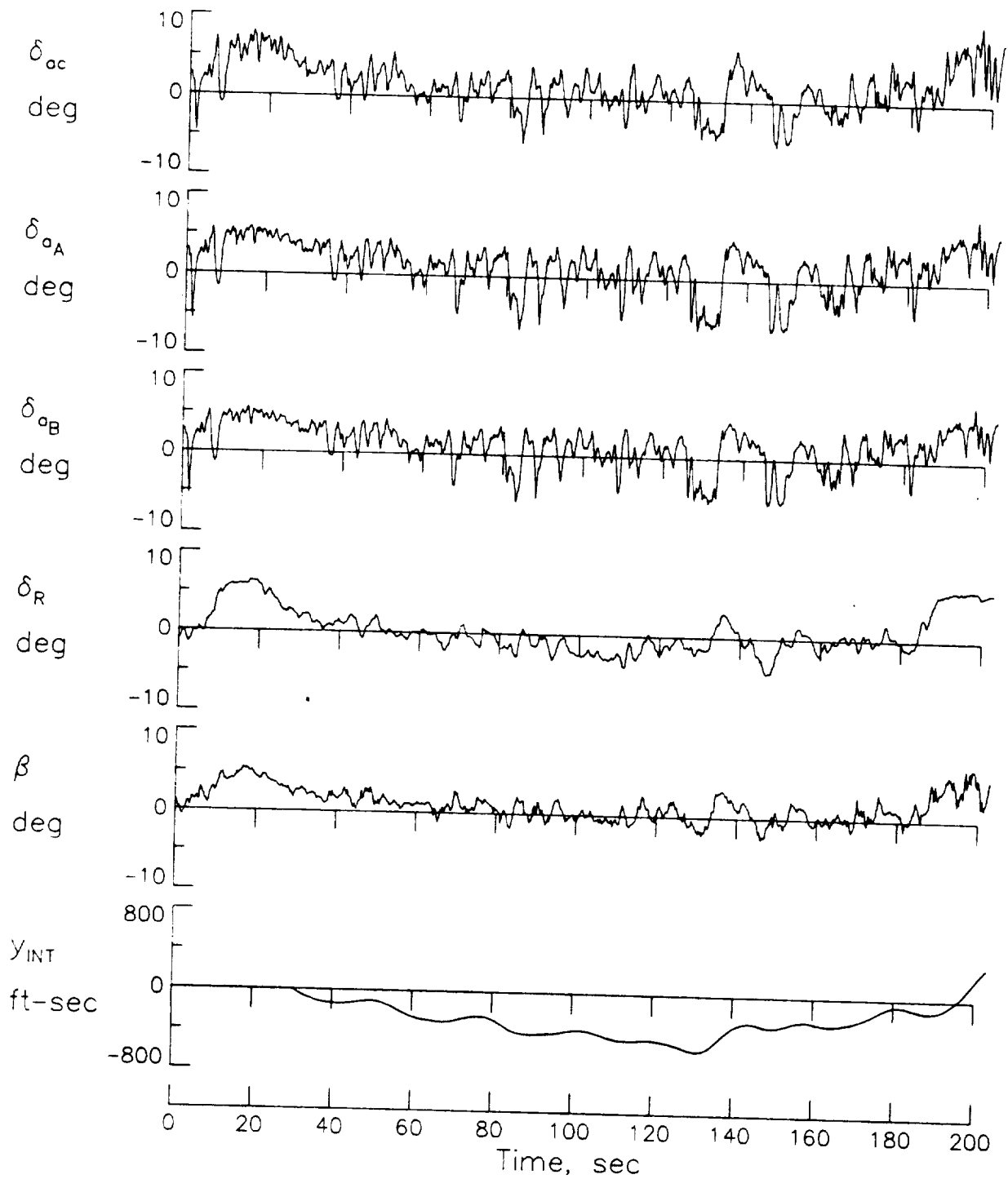


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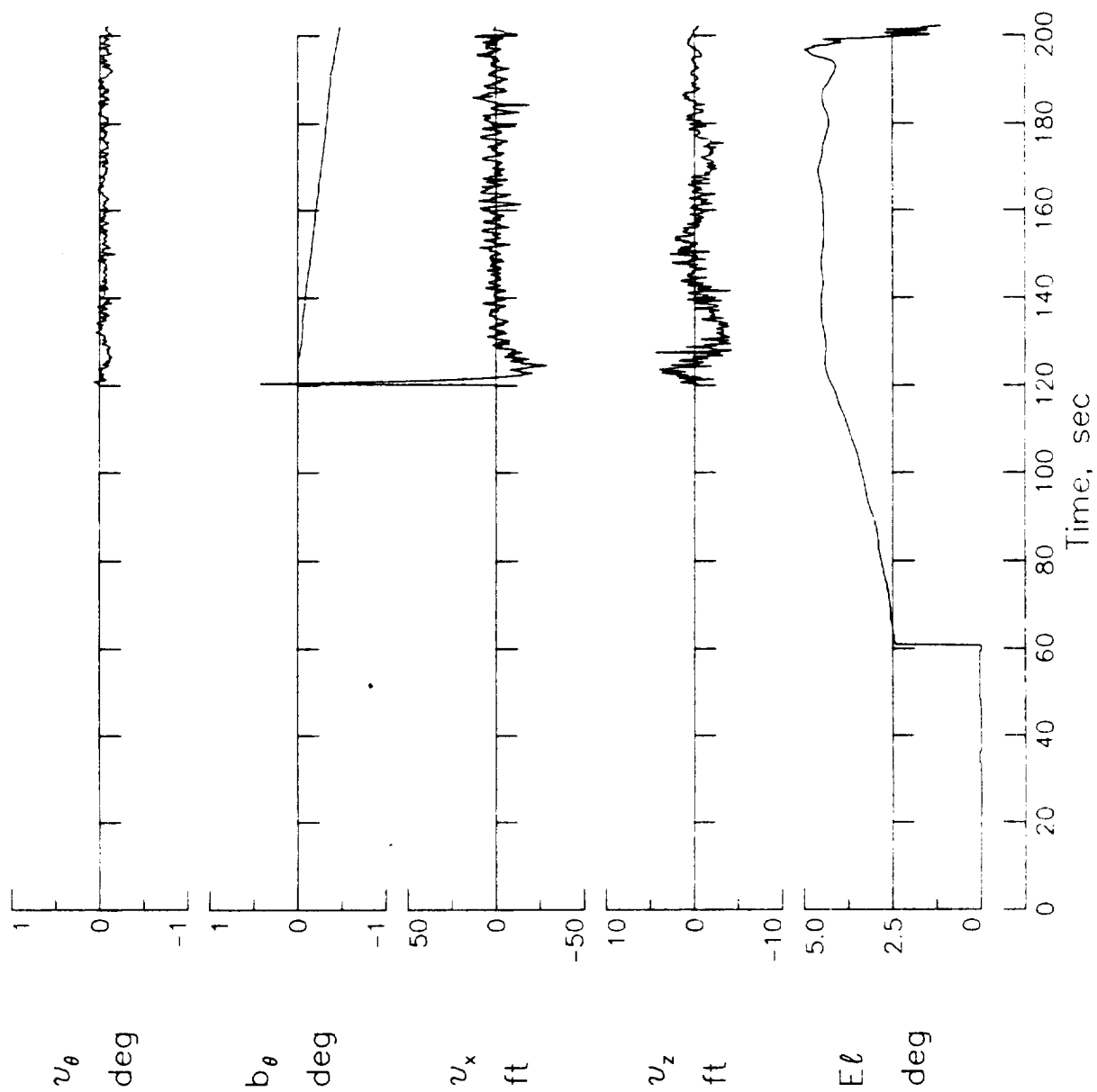


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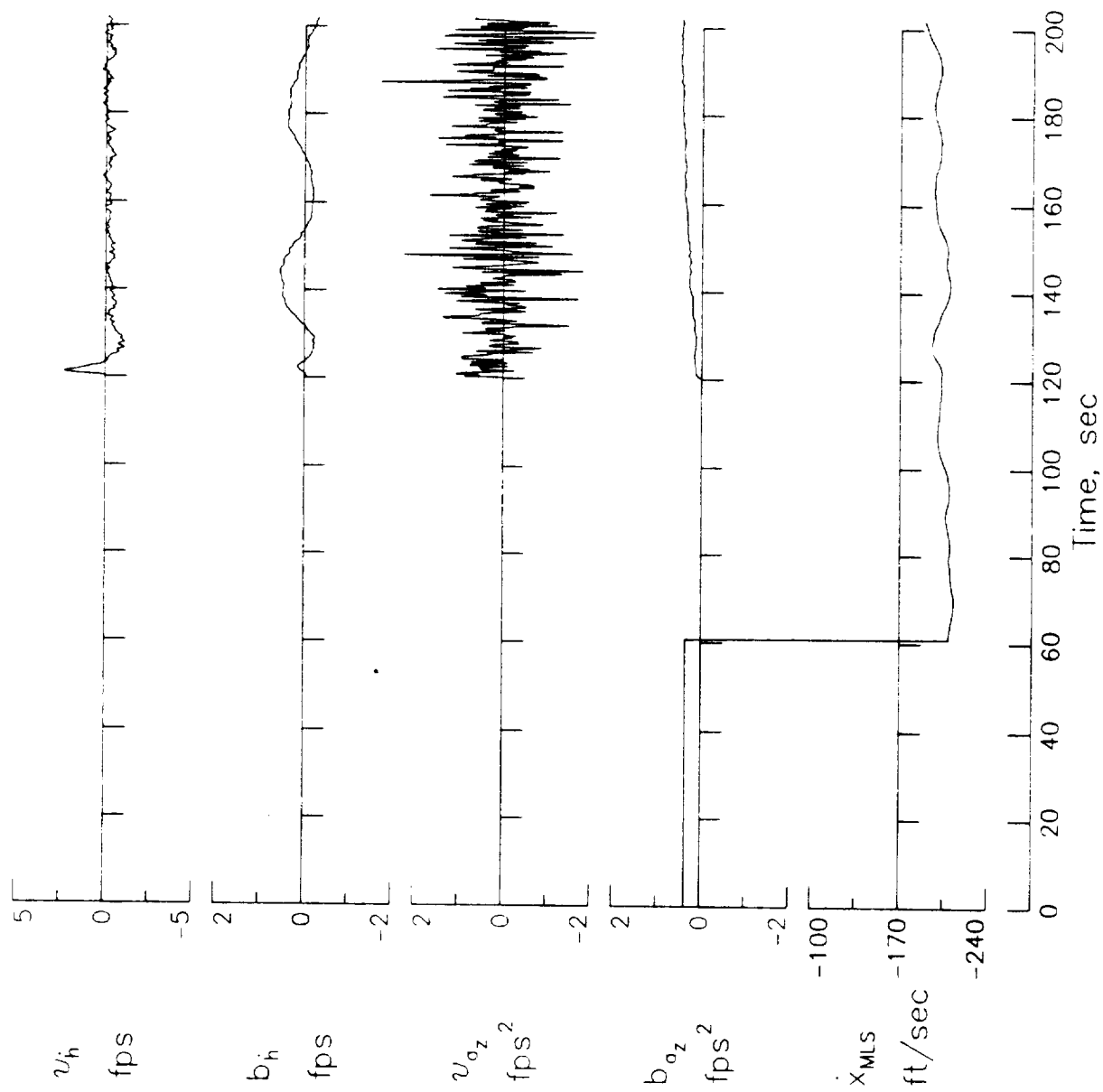


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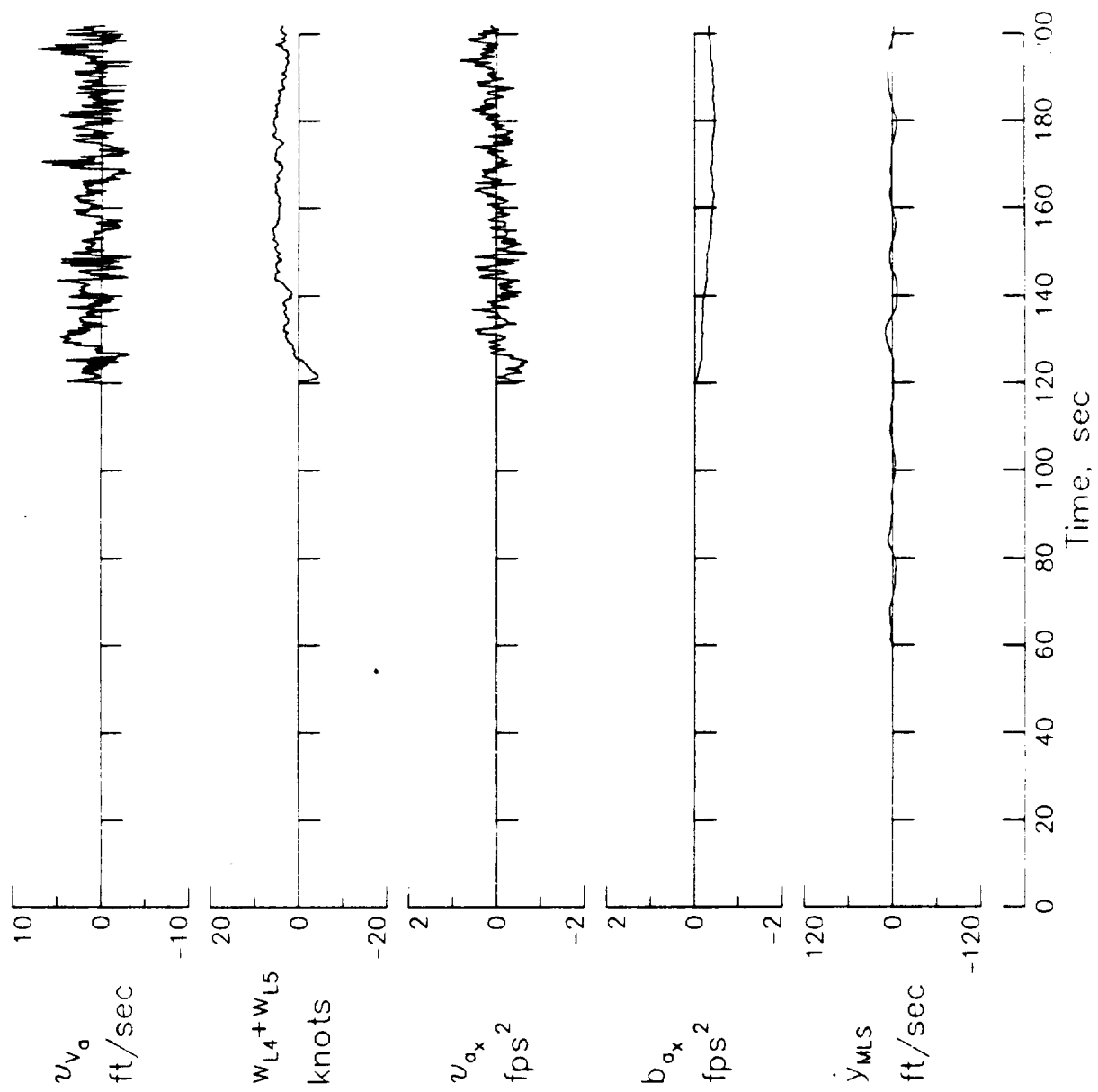


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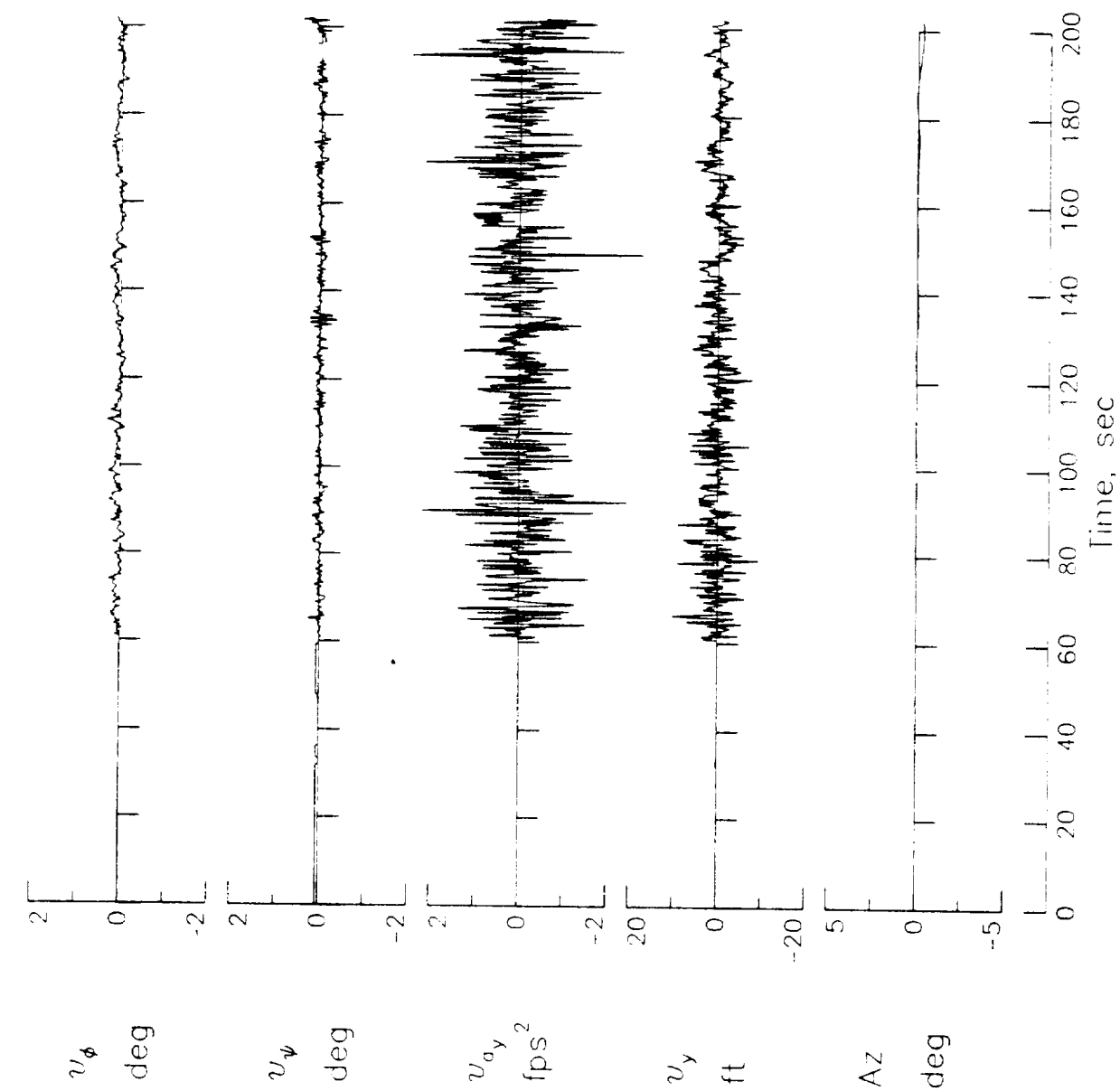


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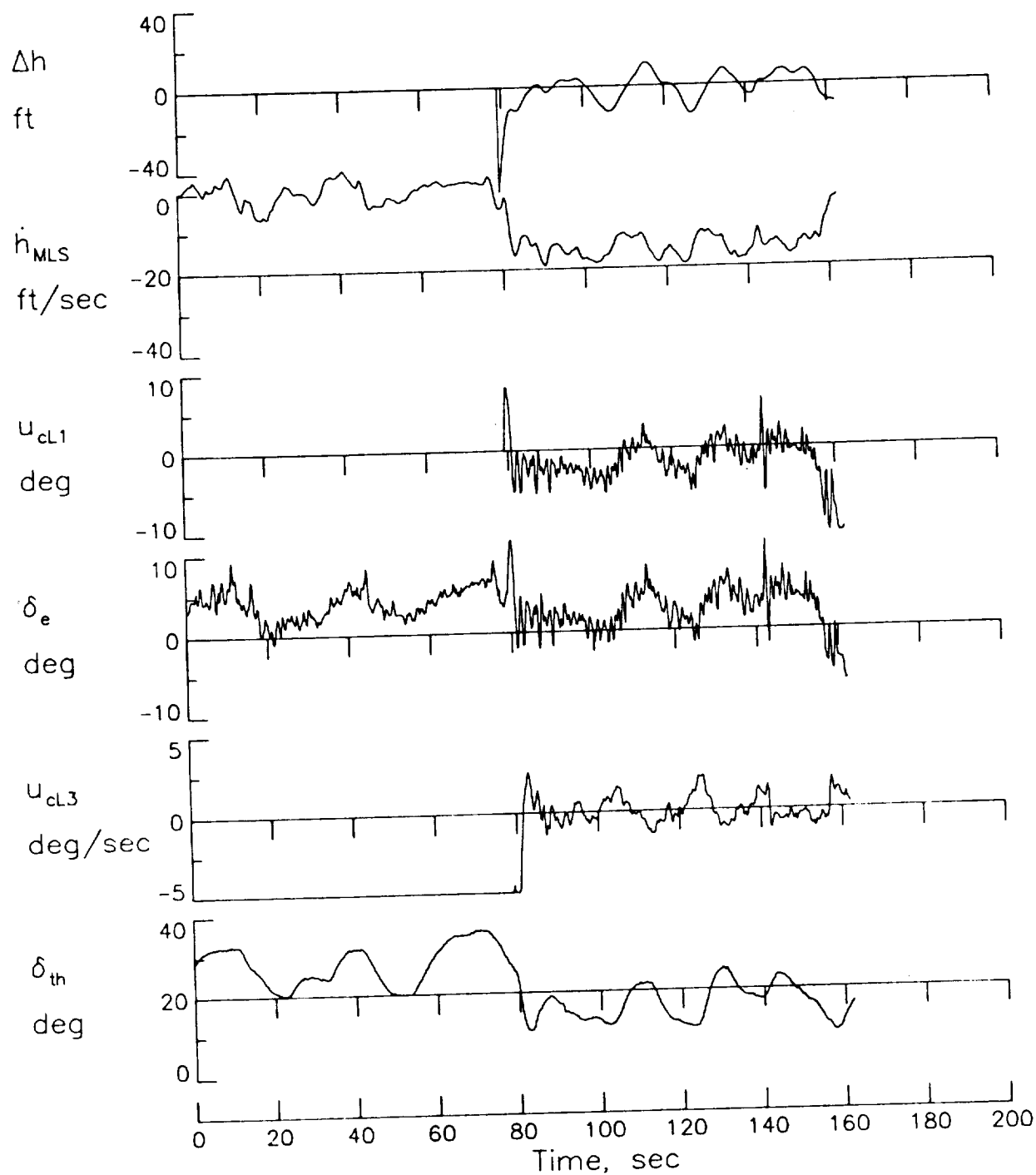


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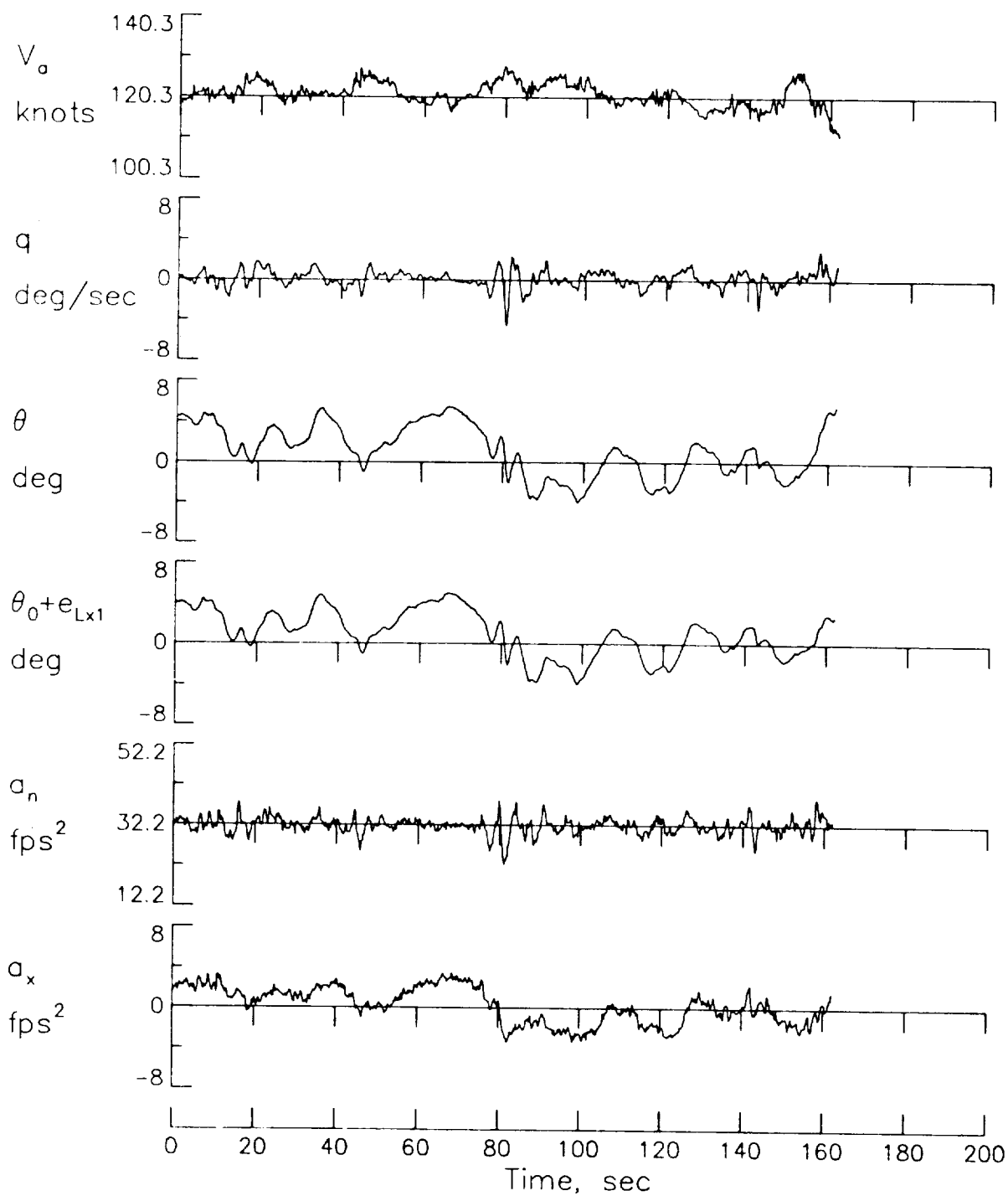


Figure 7. Flight Data for DIALS Flight Test R353, Run 7R1

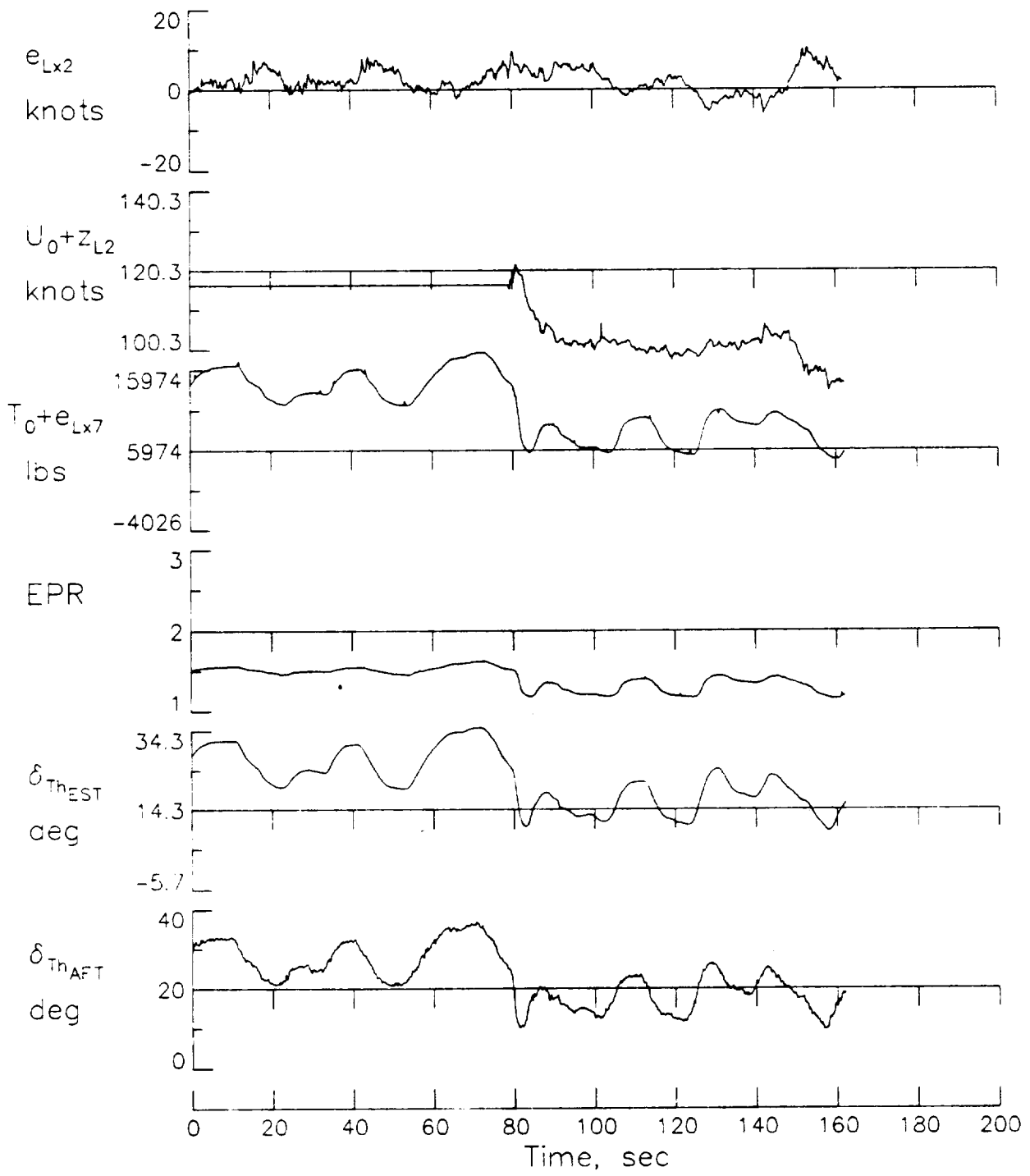


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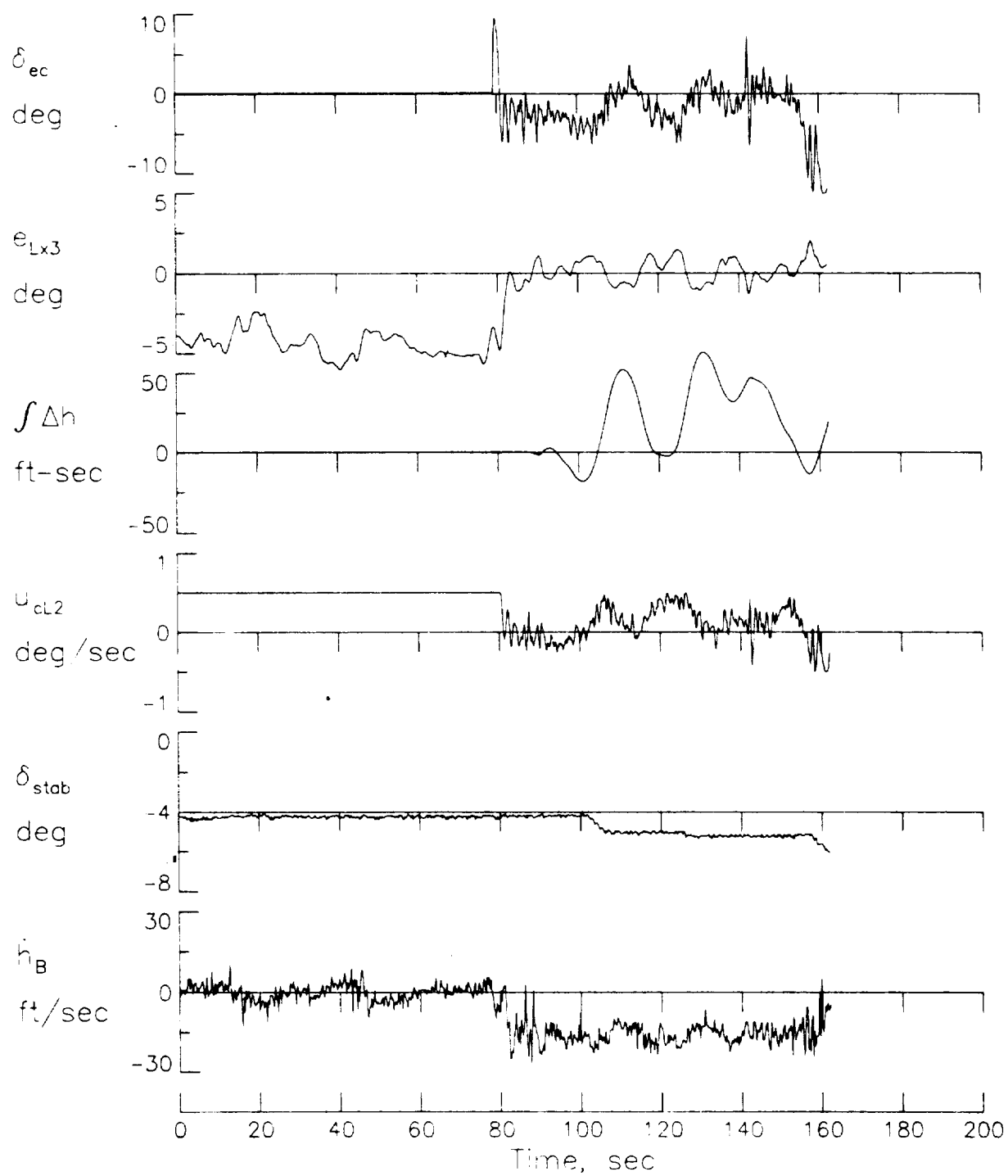


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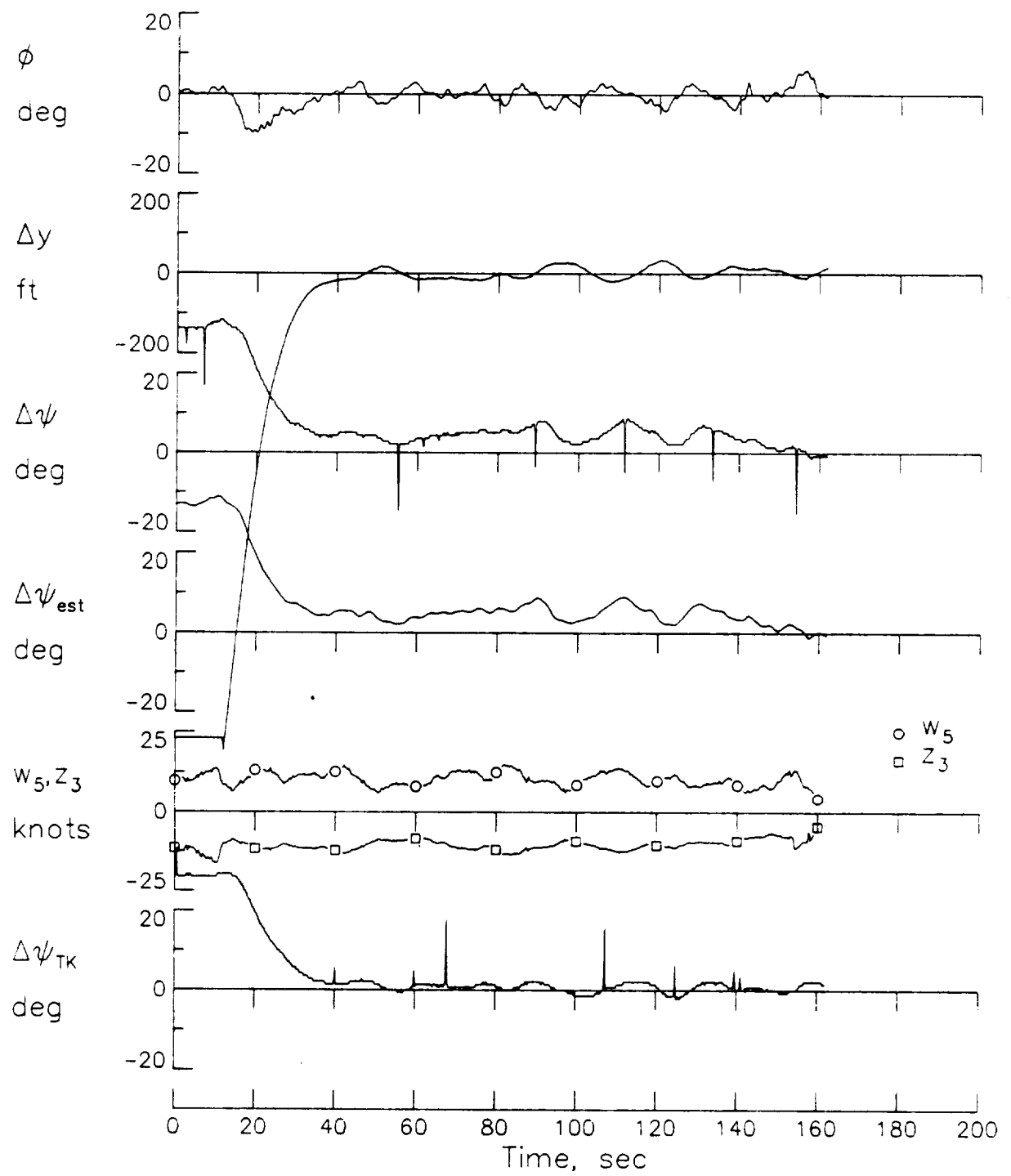


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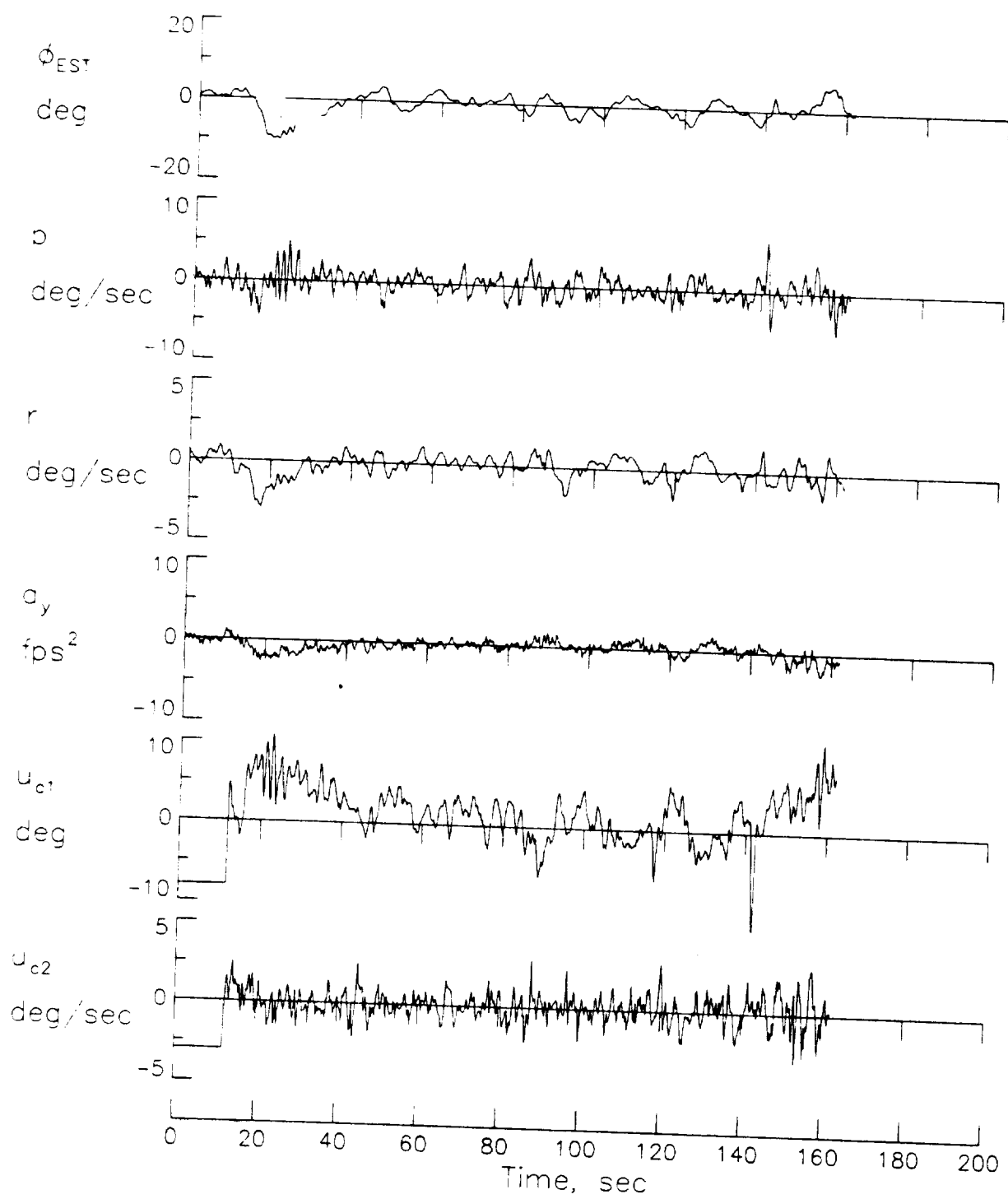


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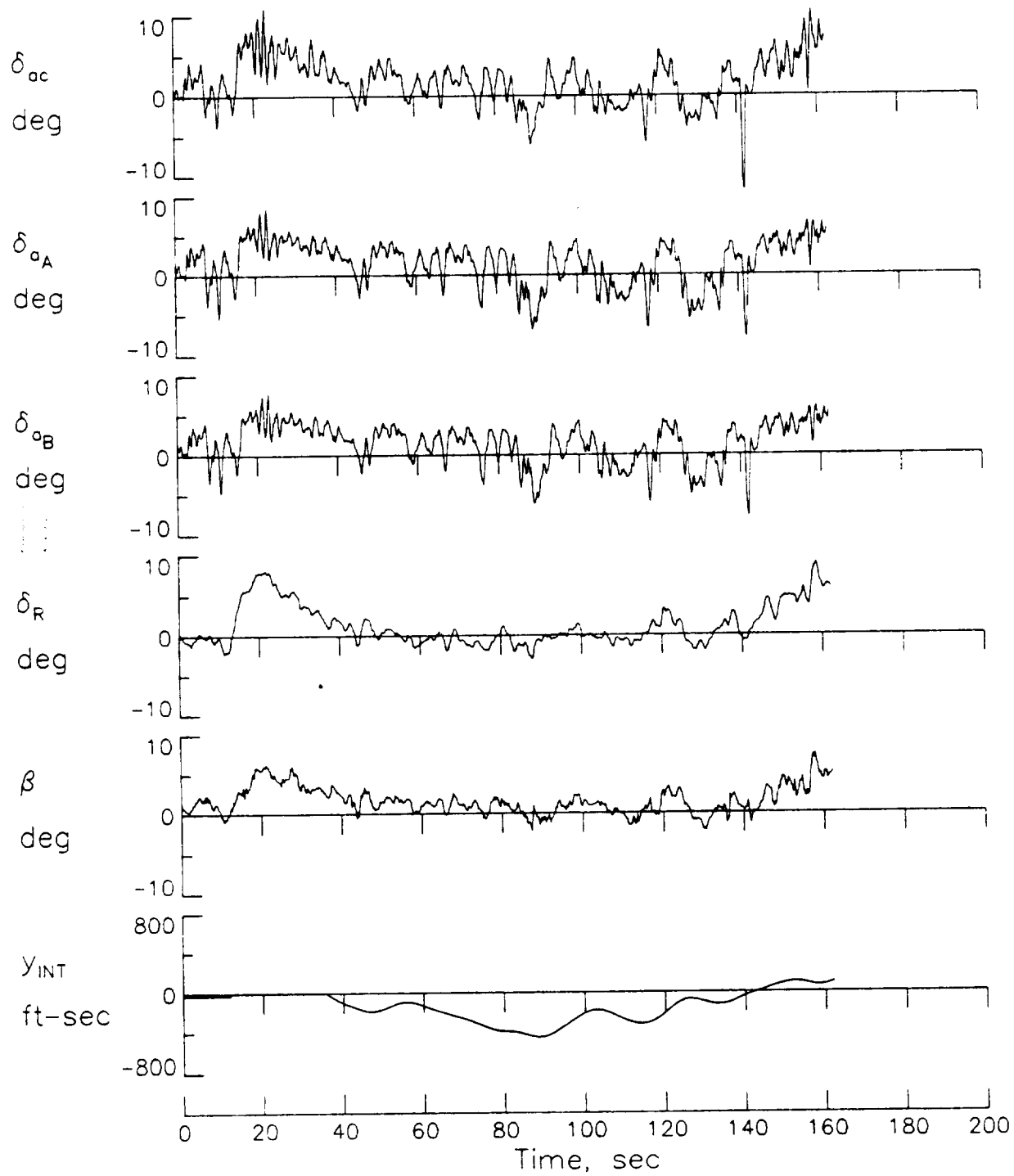


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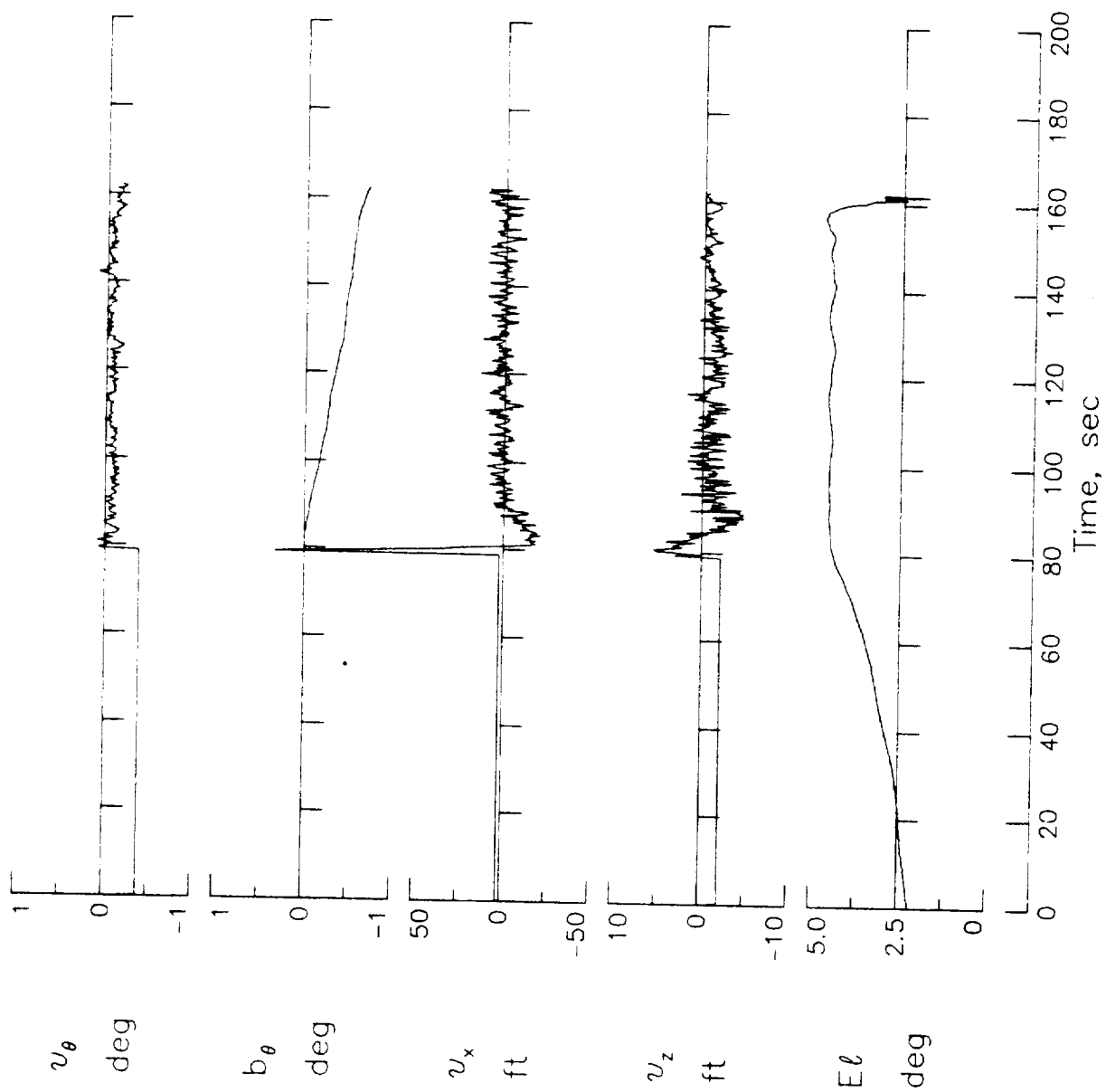


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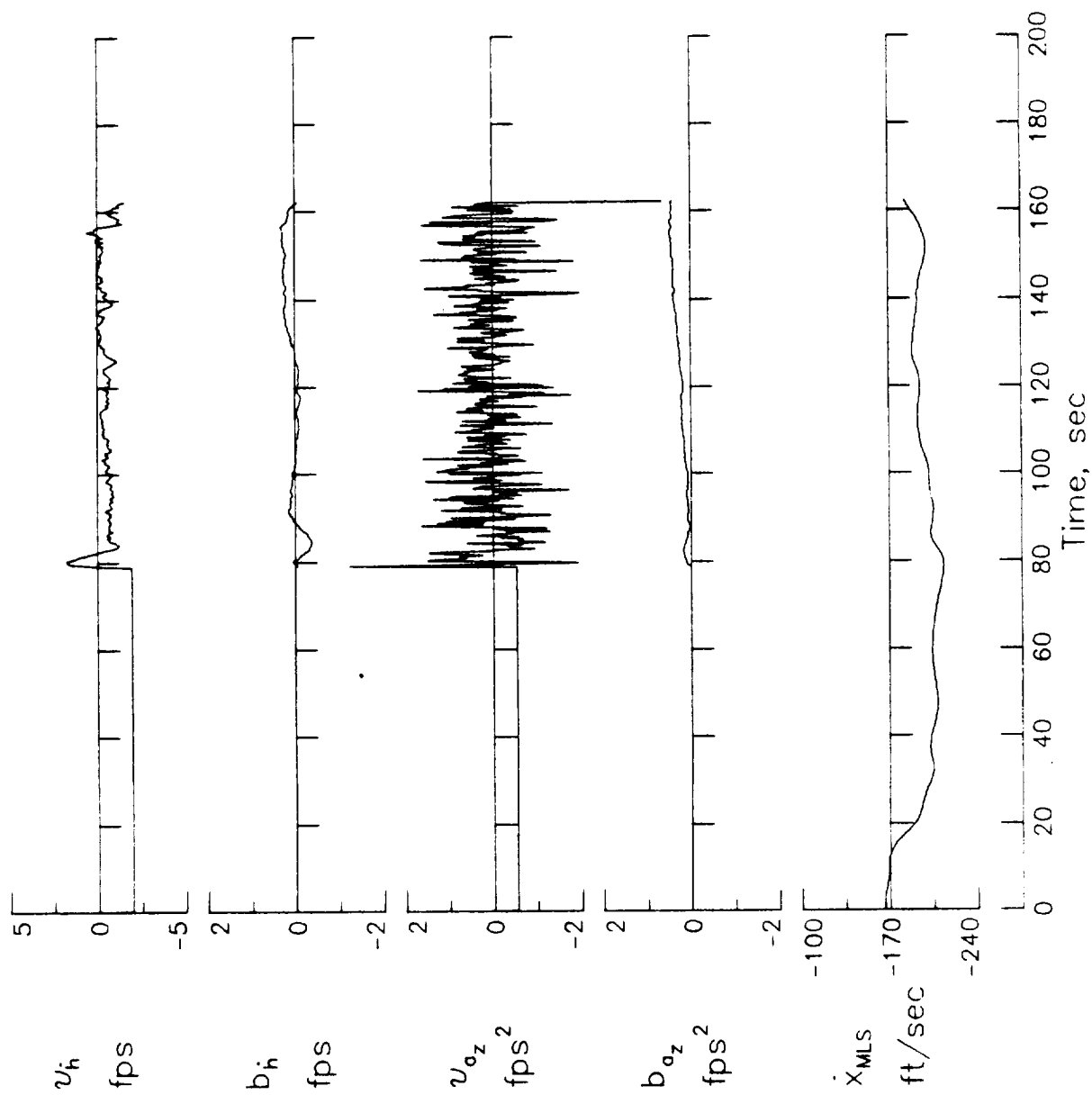


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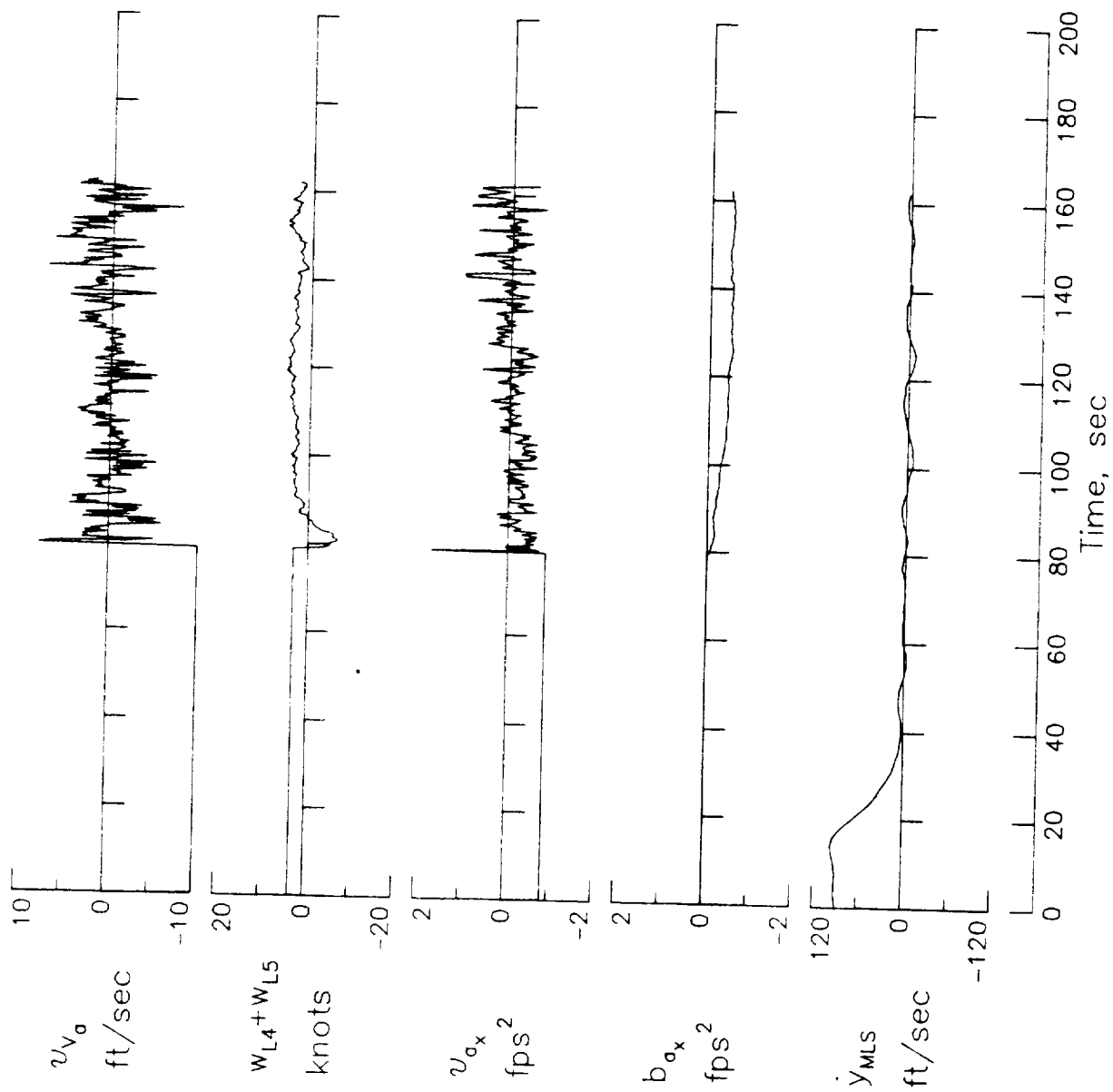


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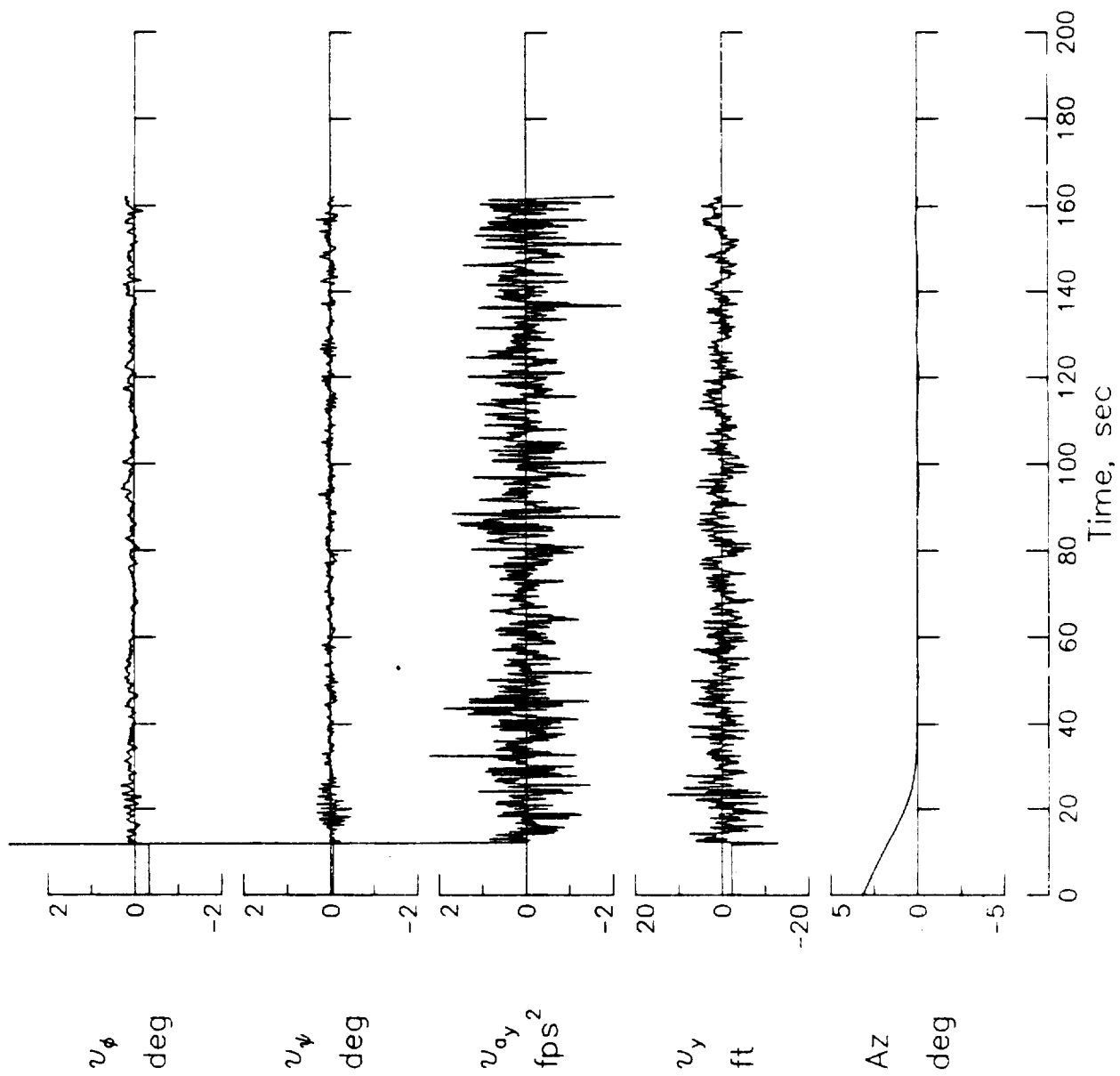


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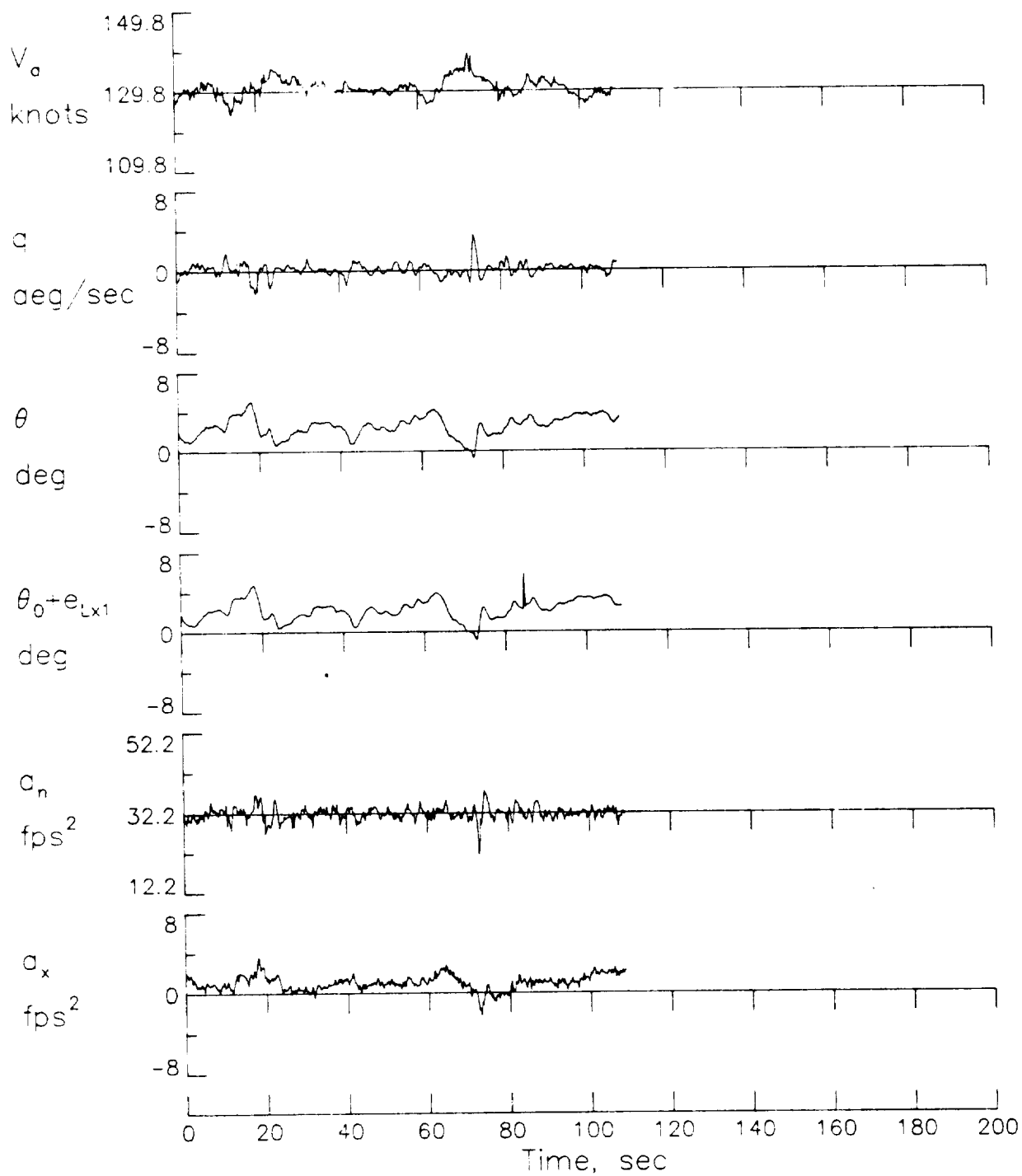


Figure 8. Flight Data for DIALS Flight Test
R355, Run 7

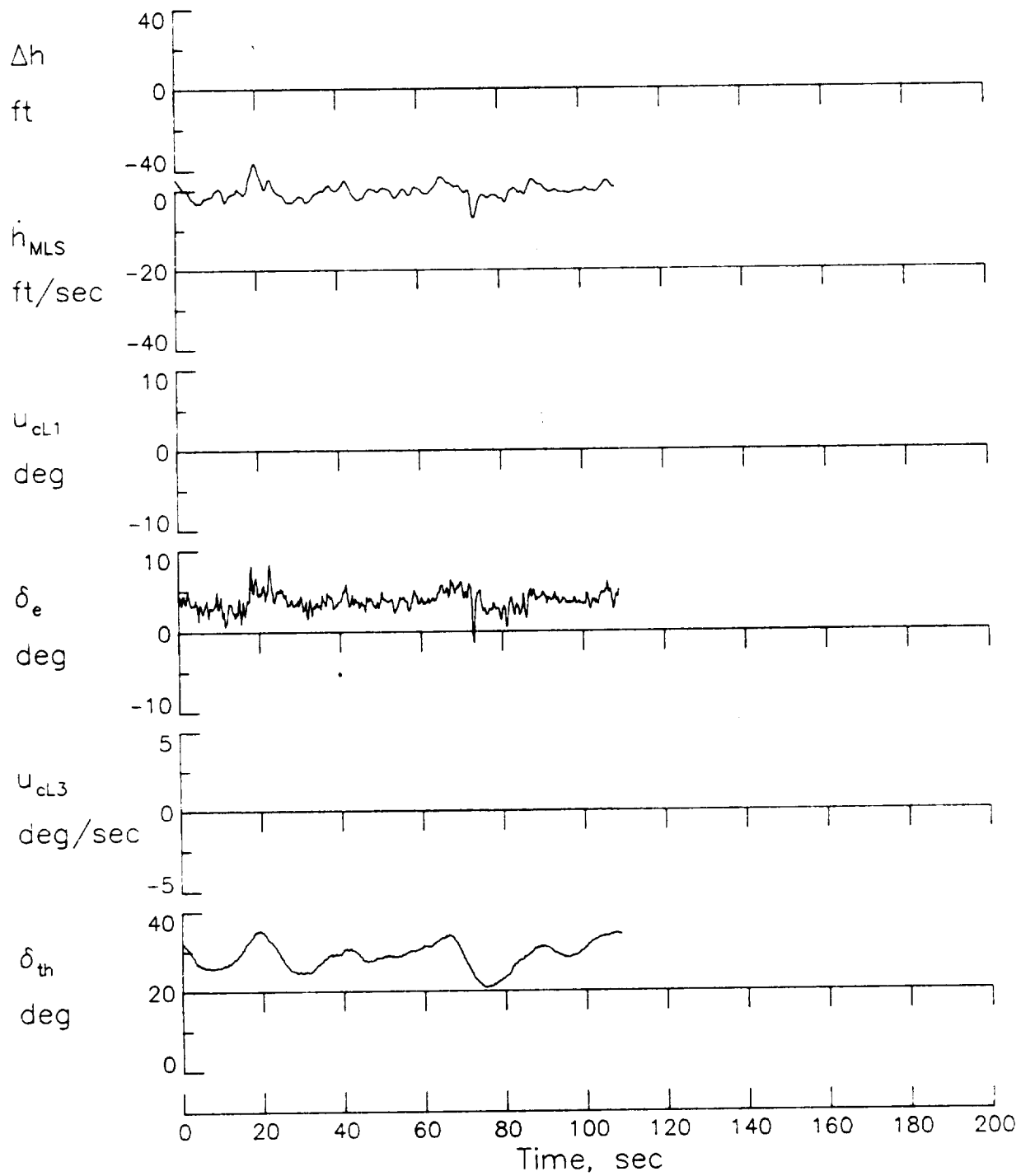


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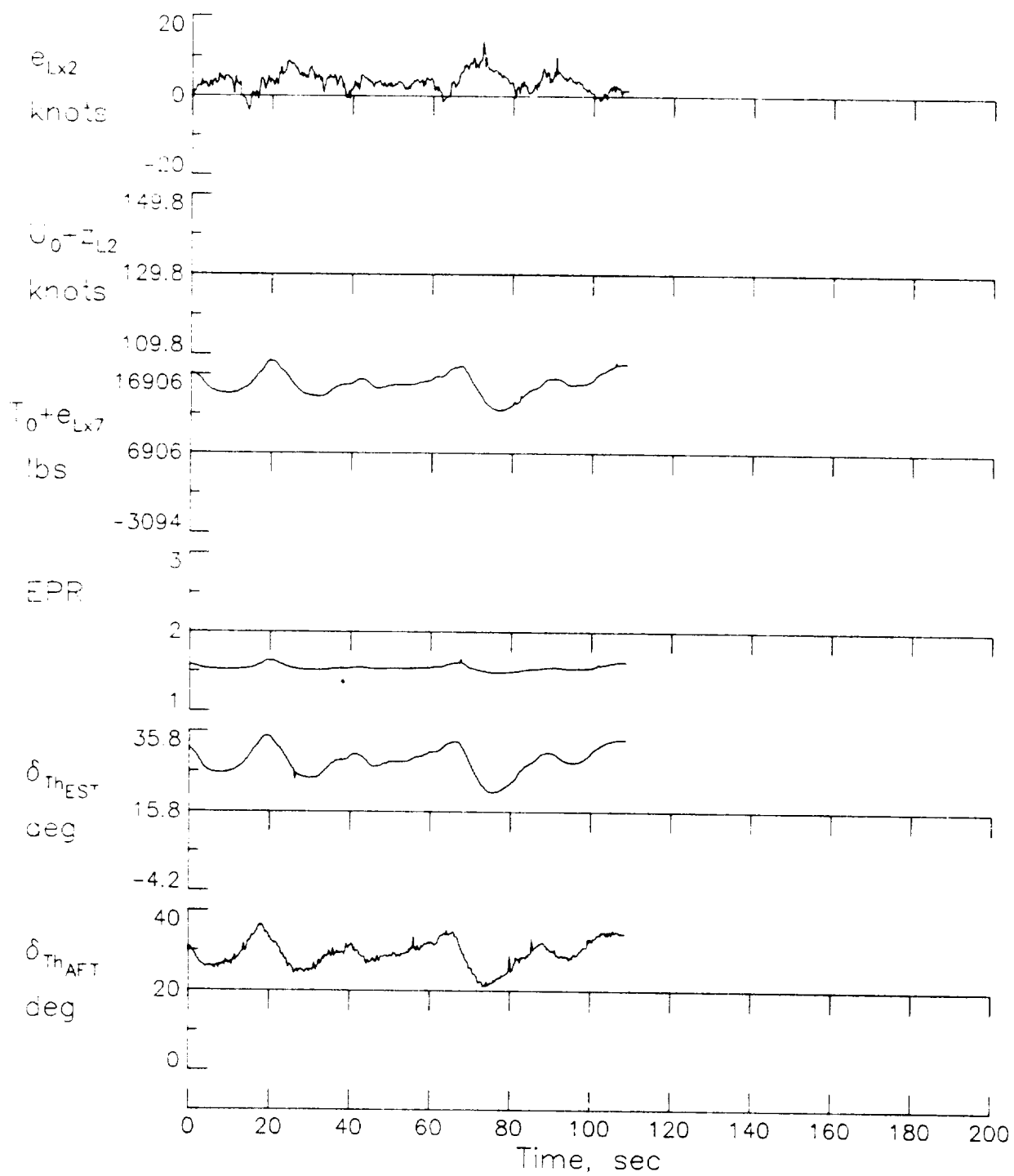


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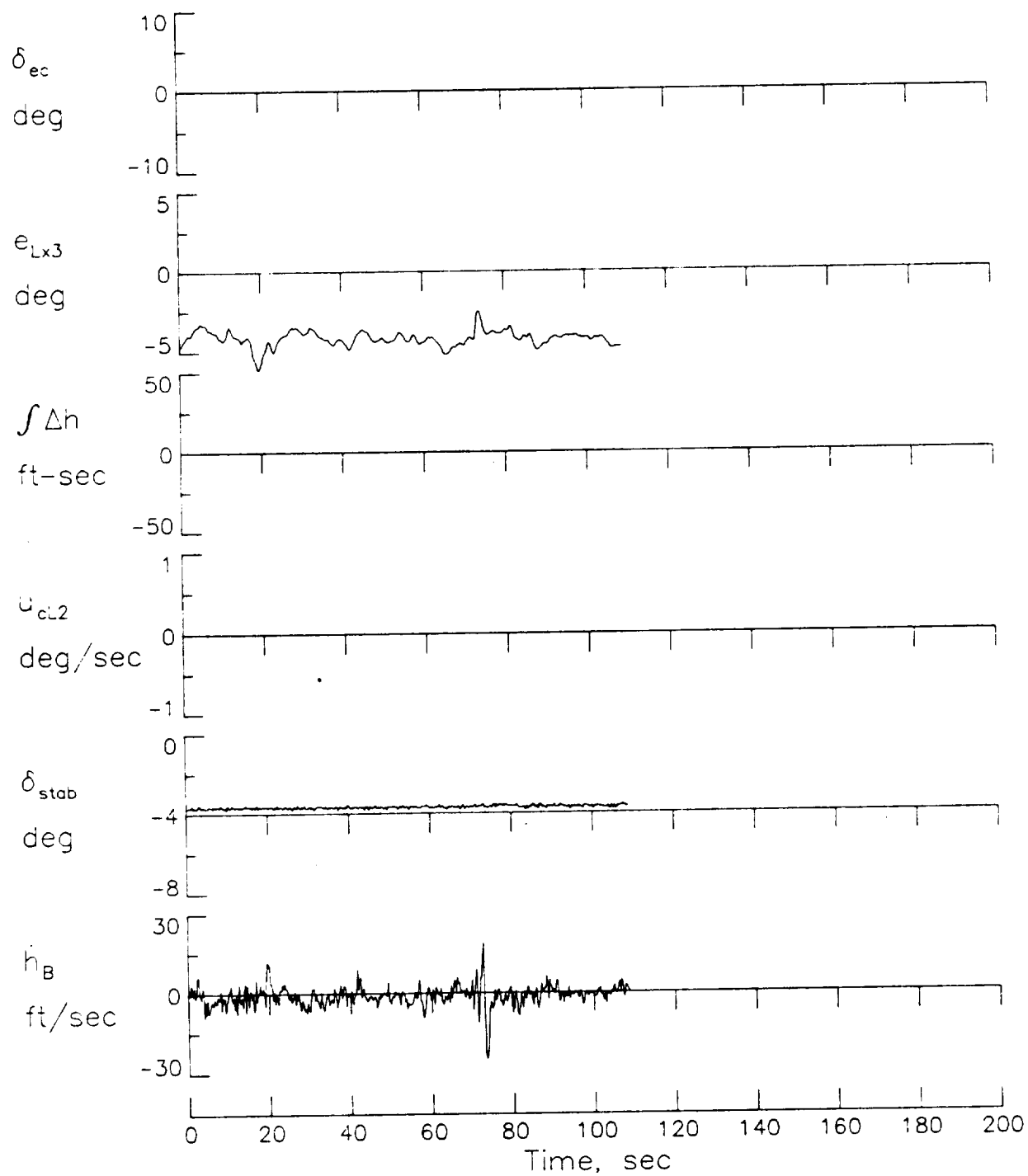


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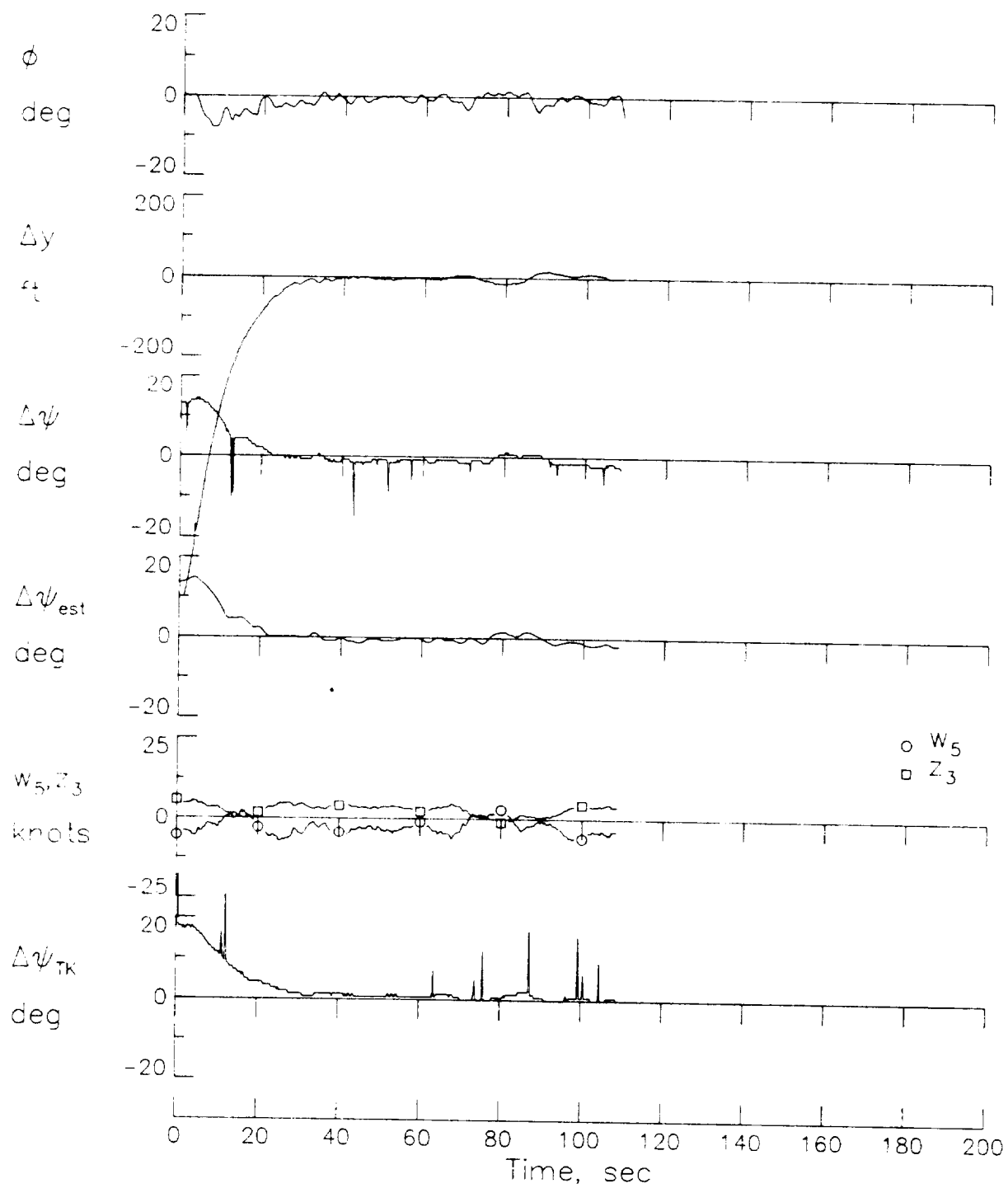


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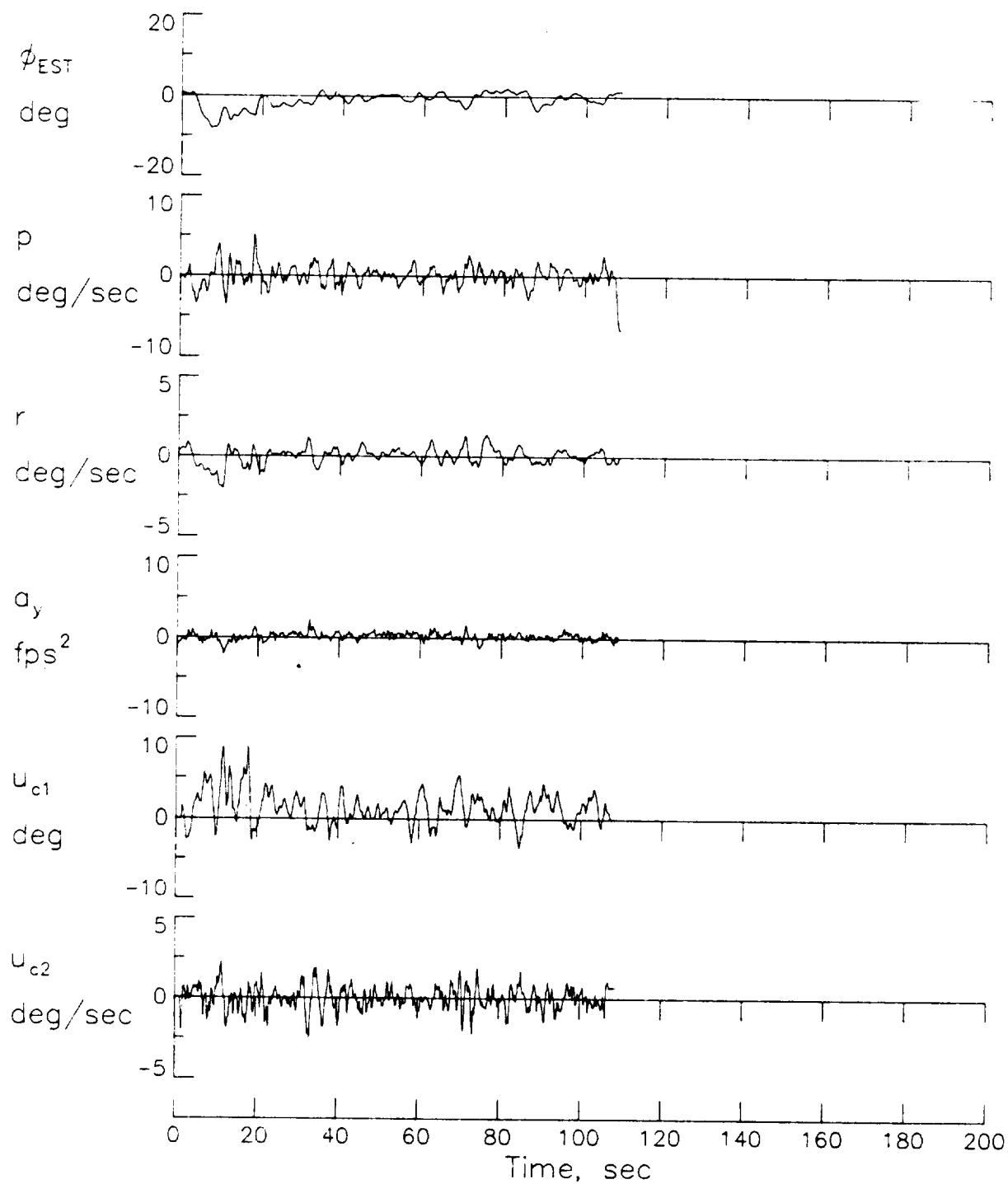


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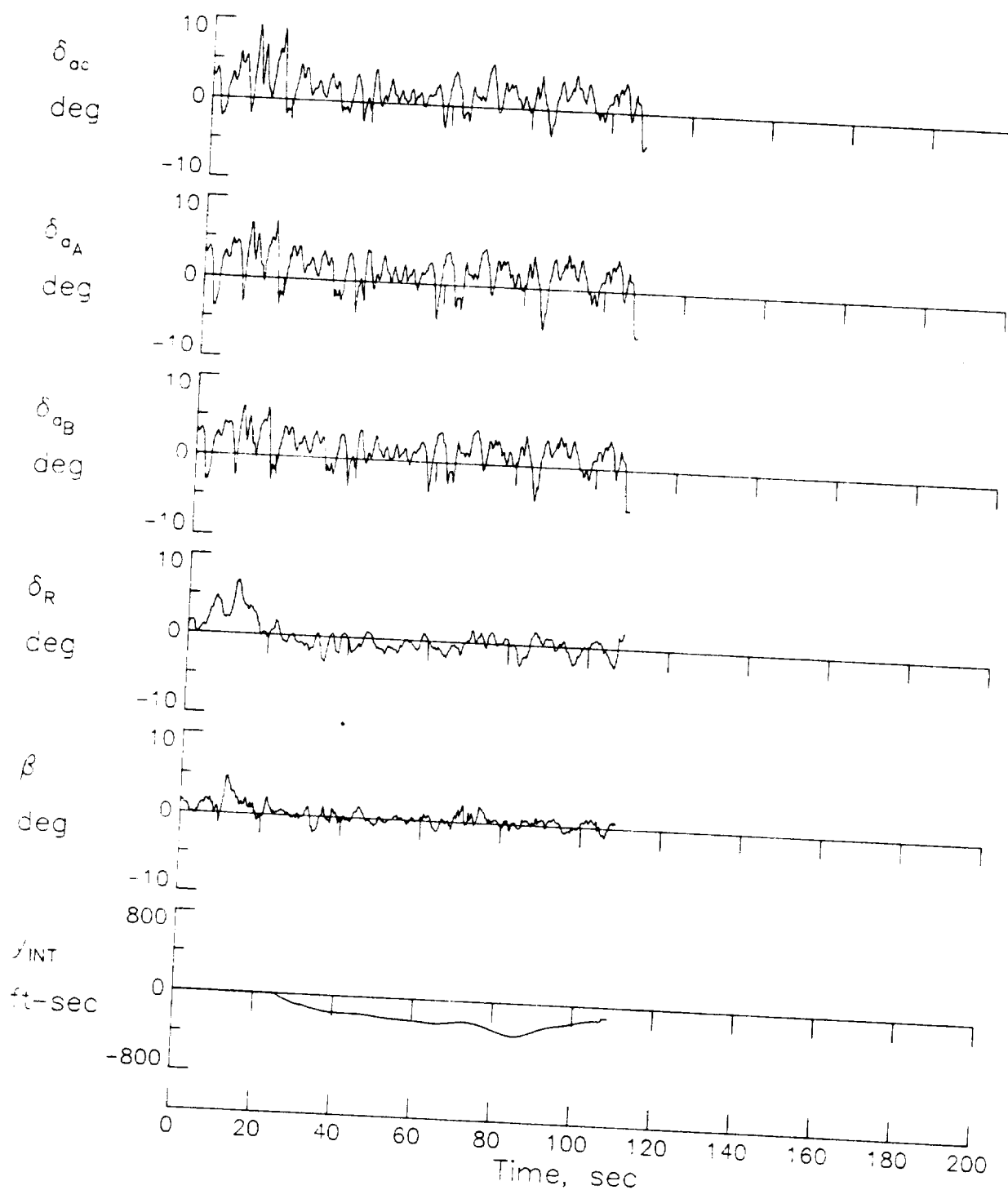


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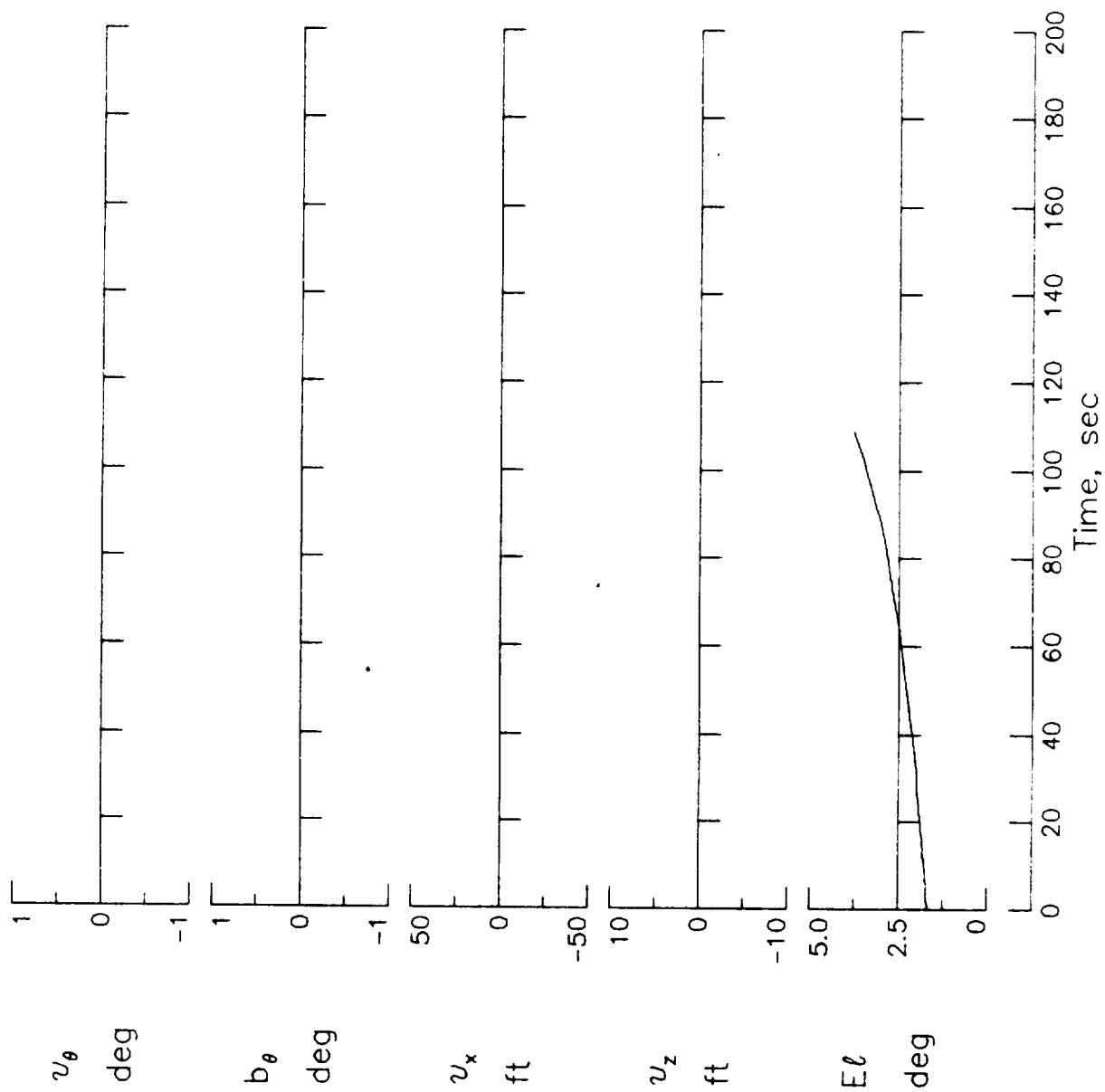


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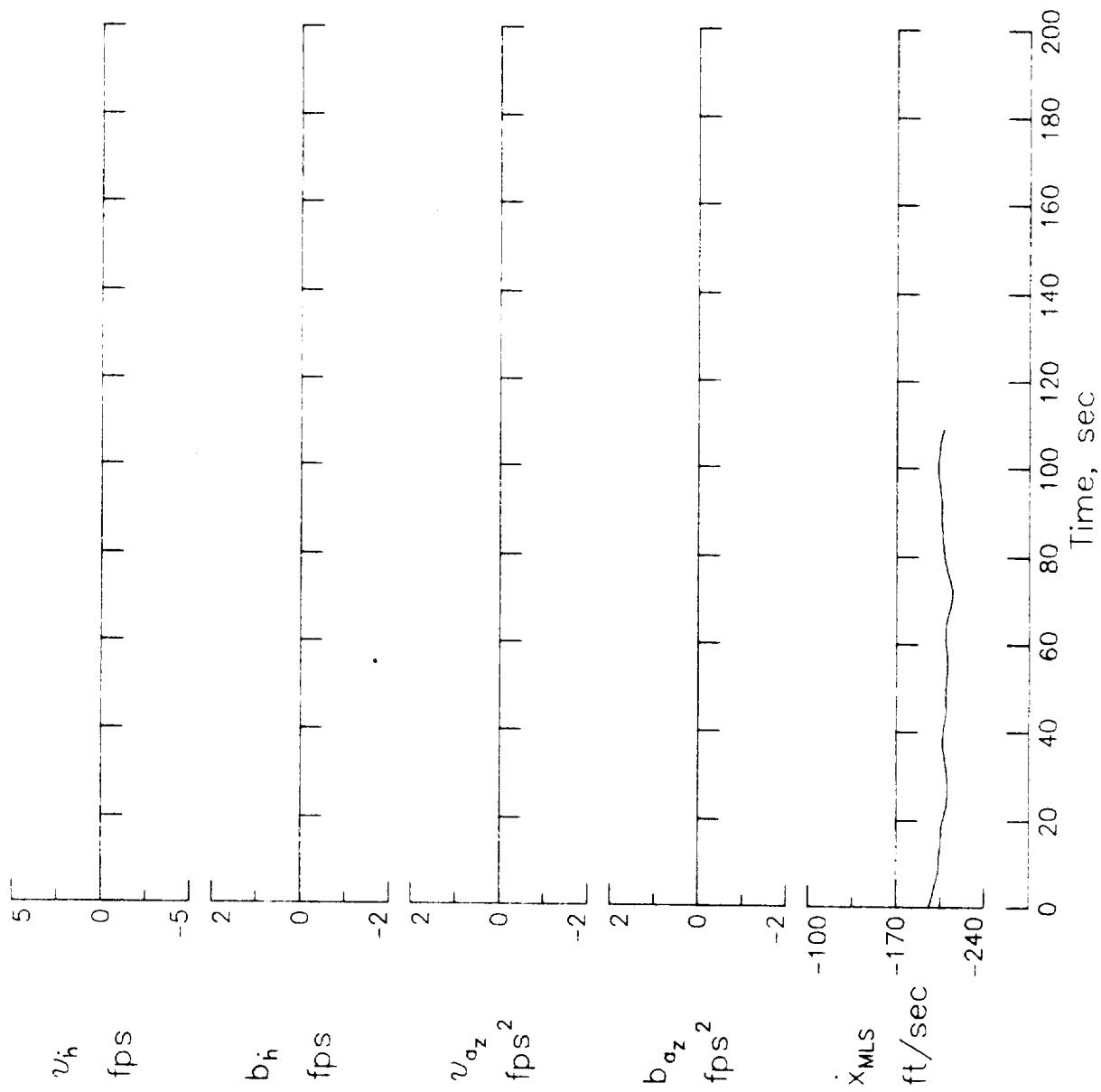


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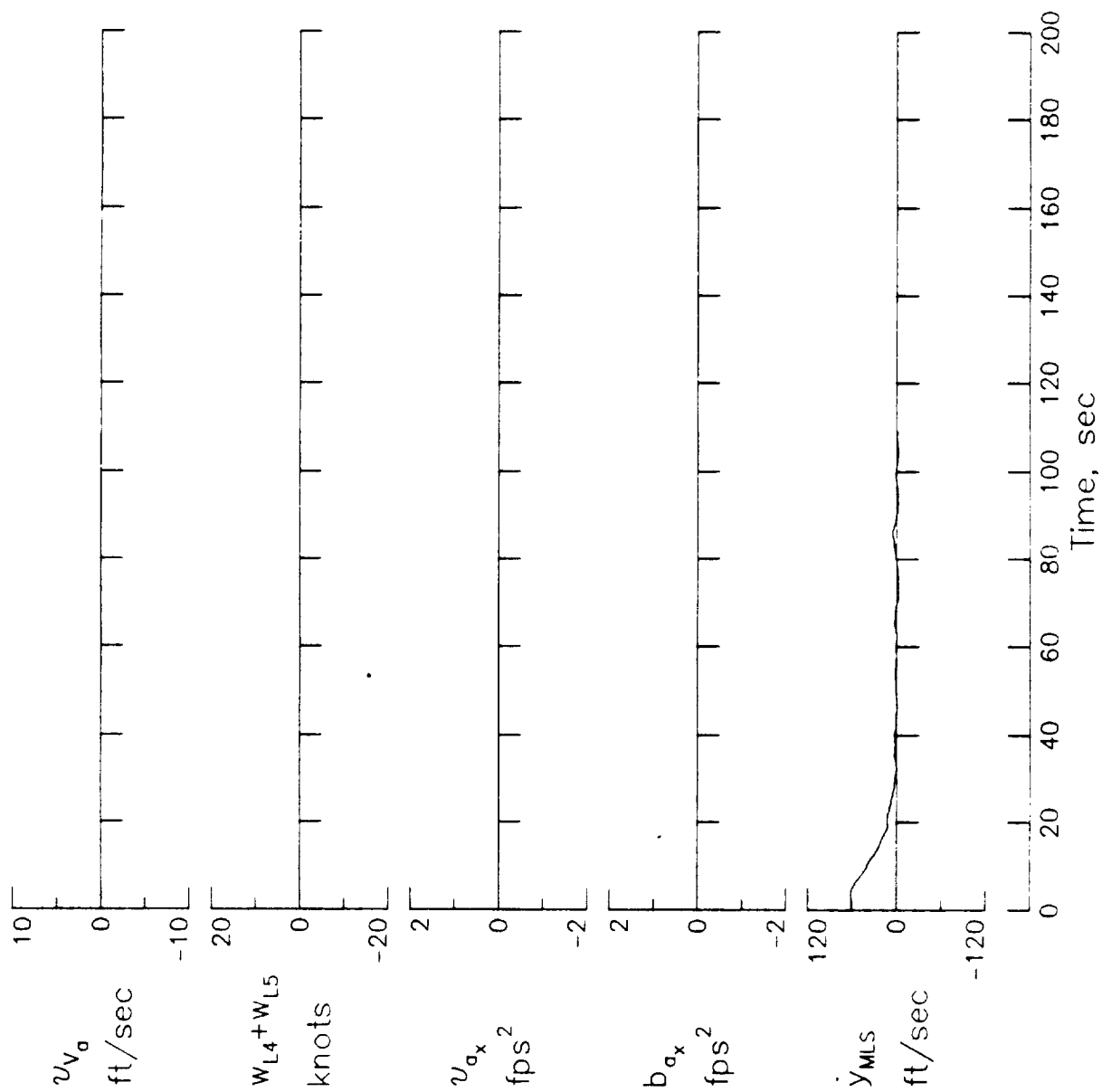


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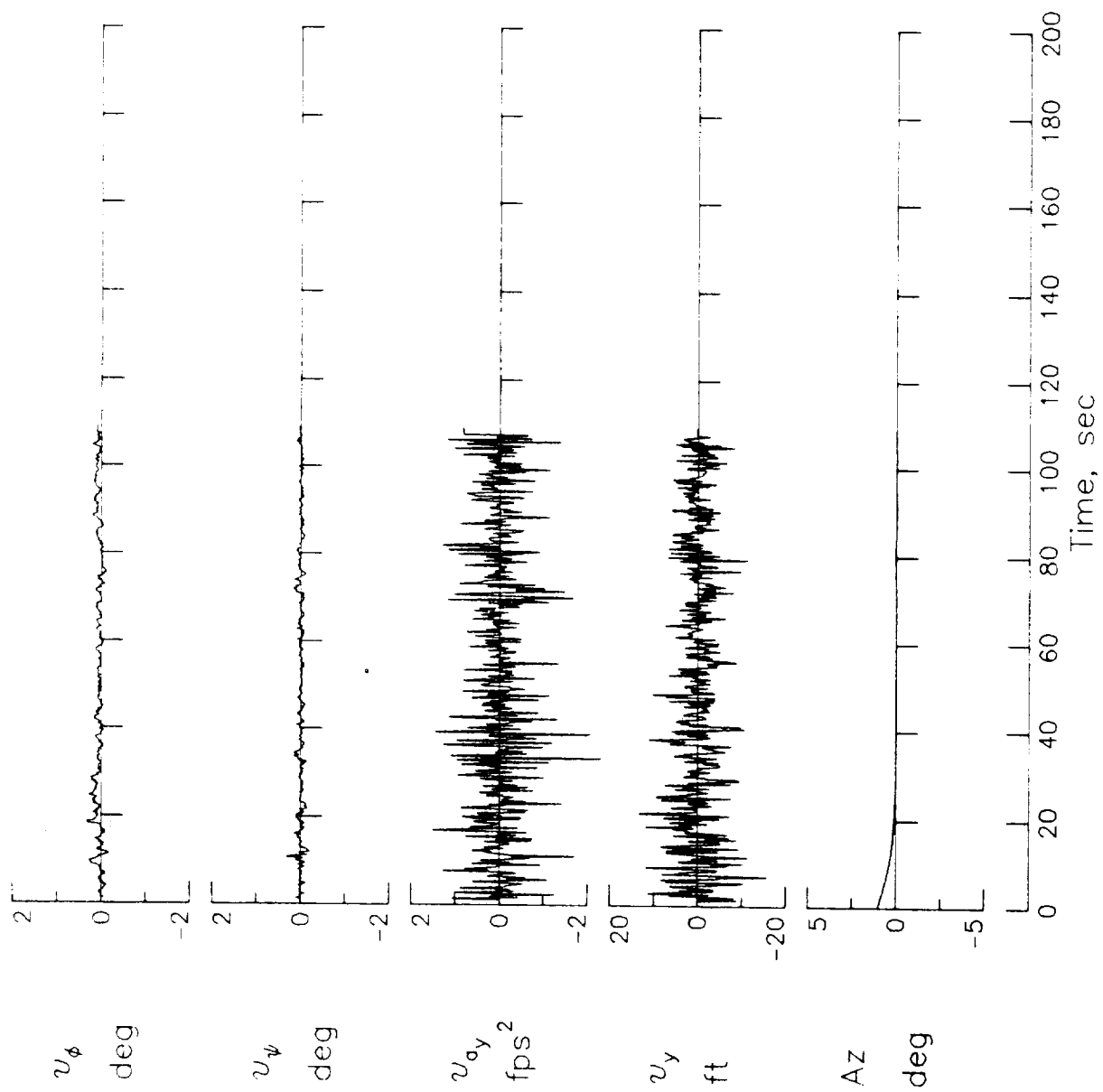


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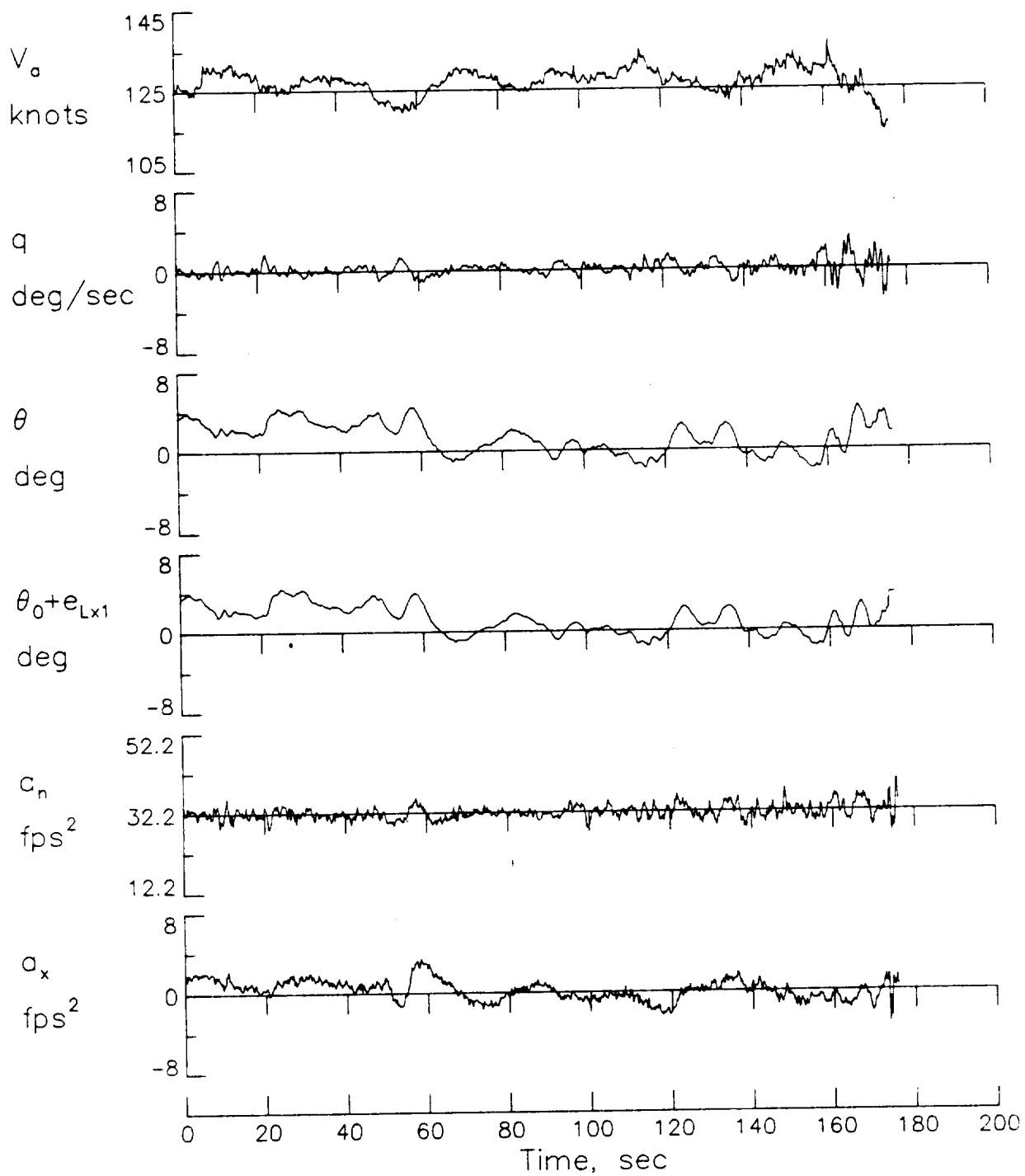


Figure 9. Flight Data for DIALS Flight Test
R355, Run 7R1

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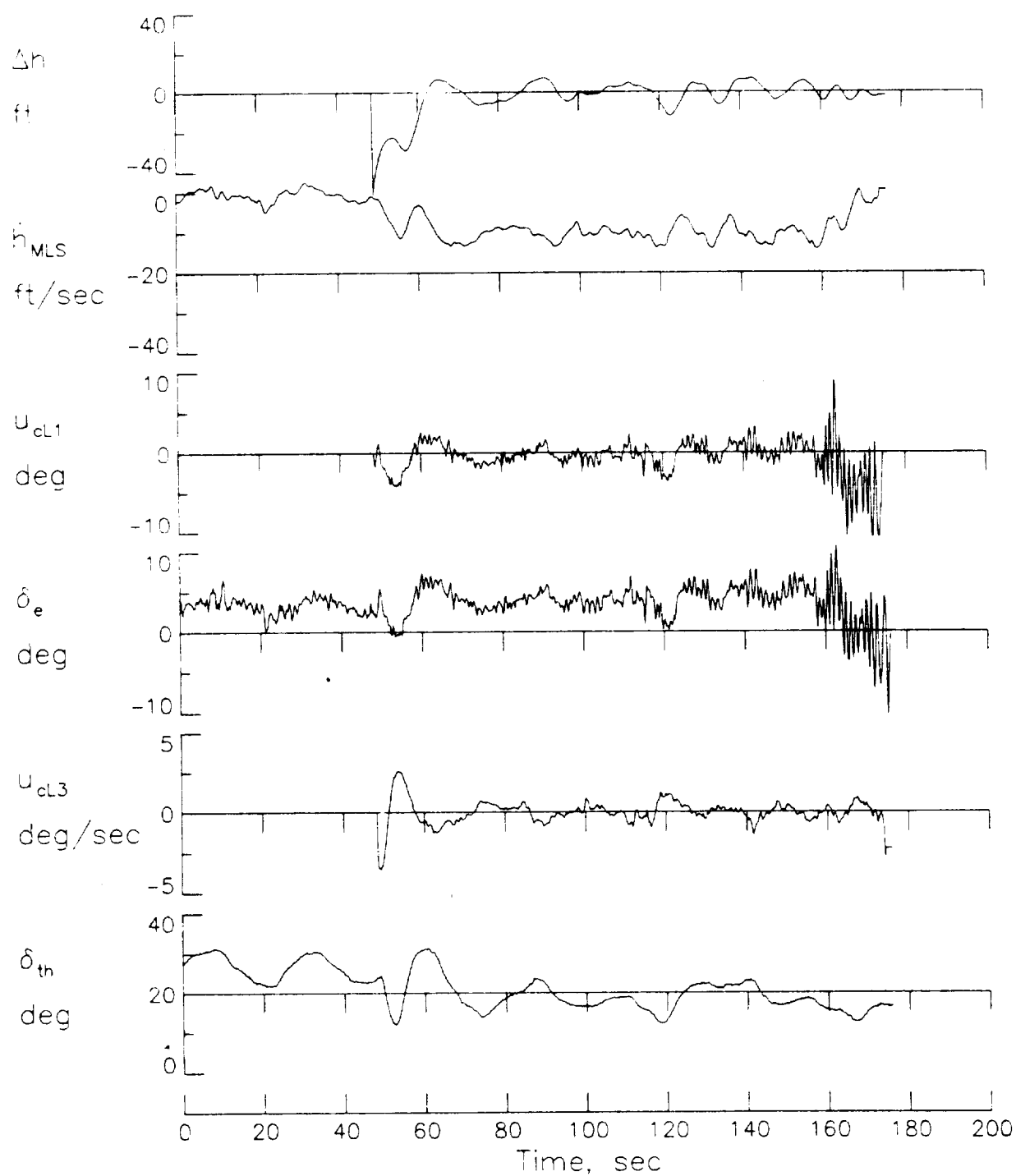


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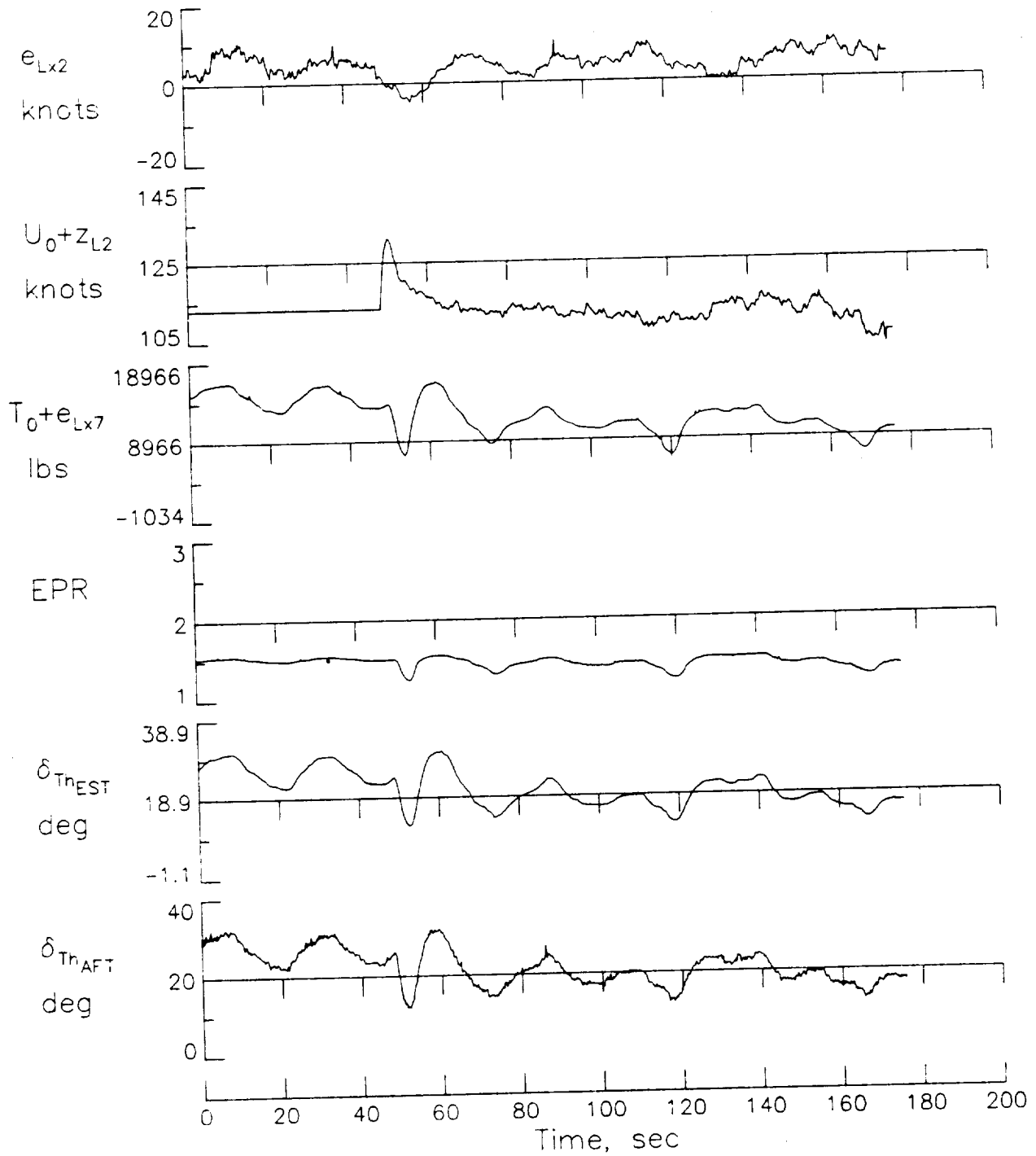


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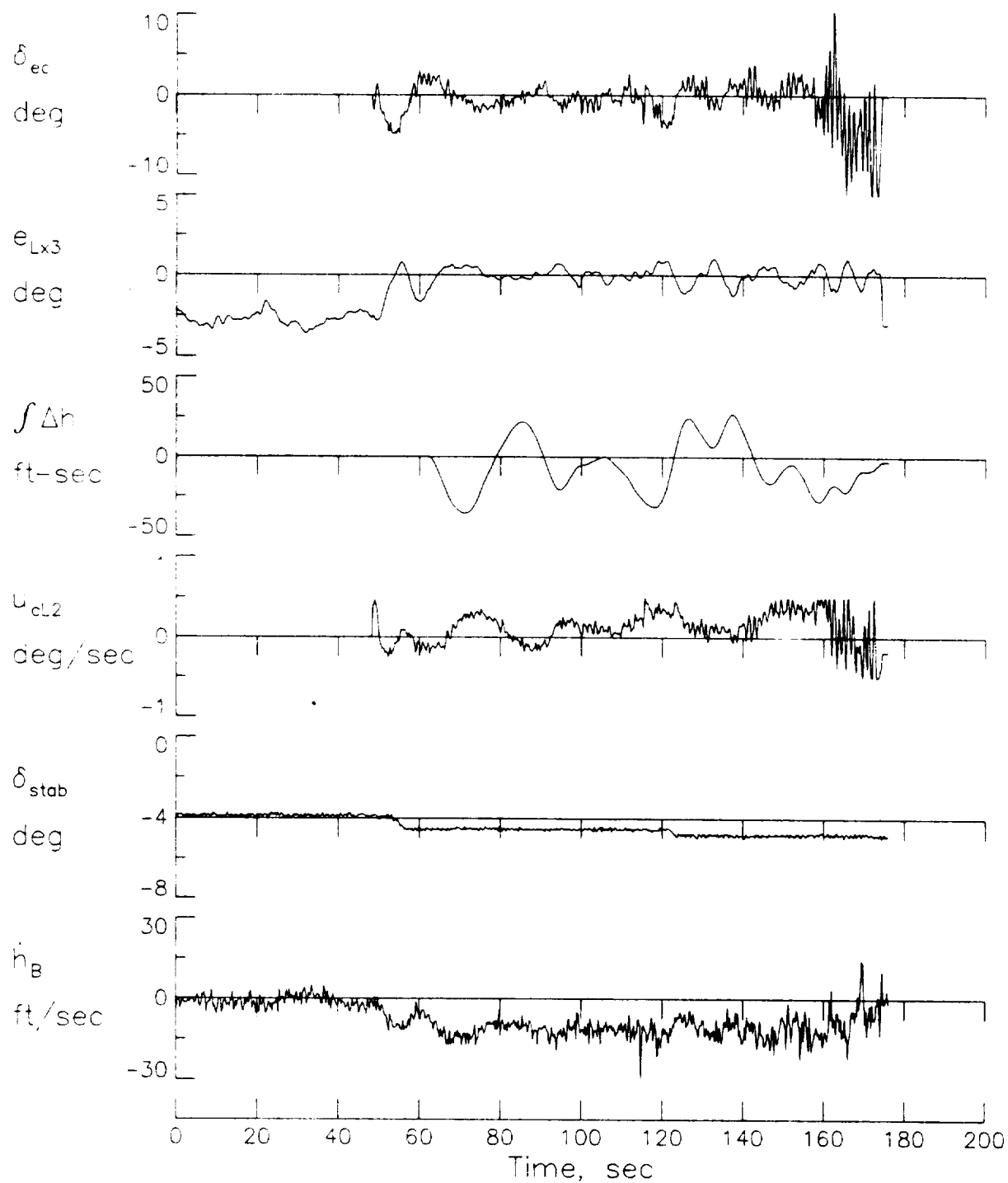


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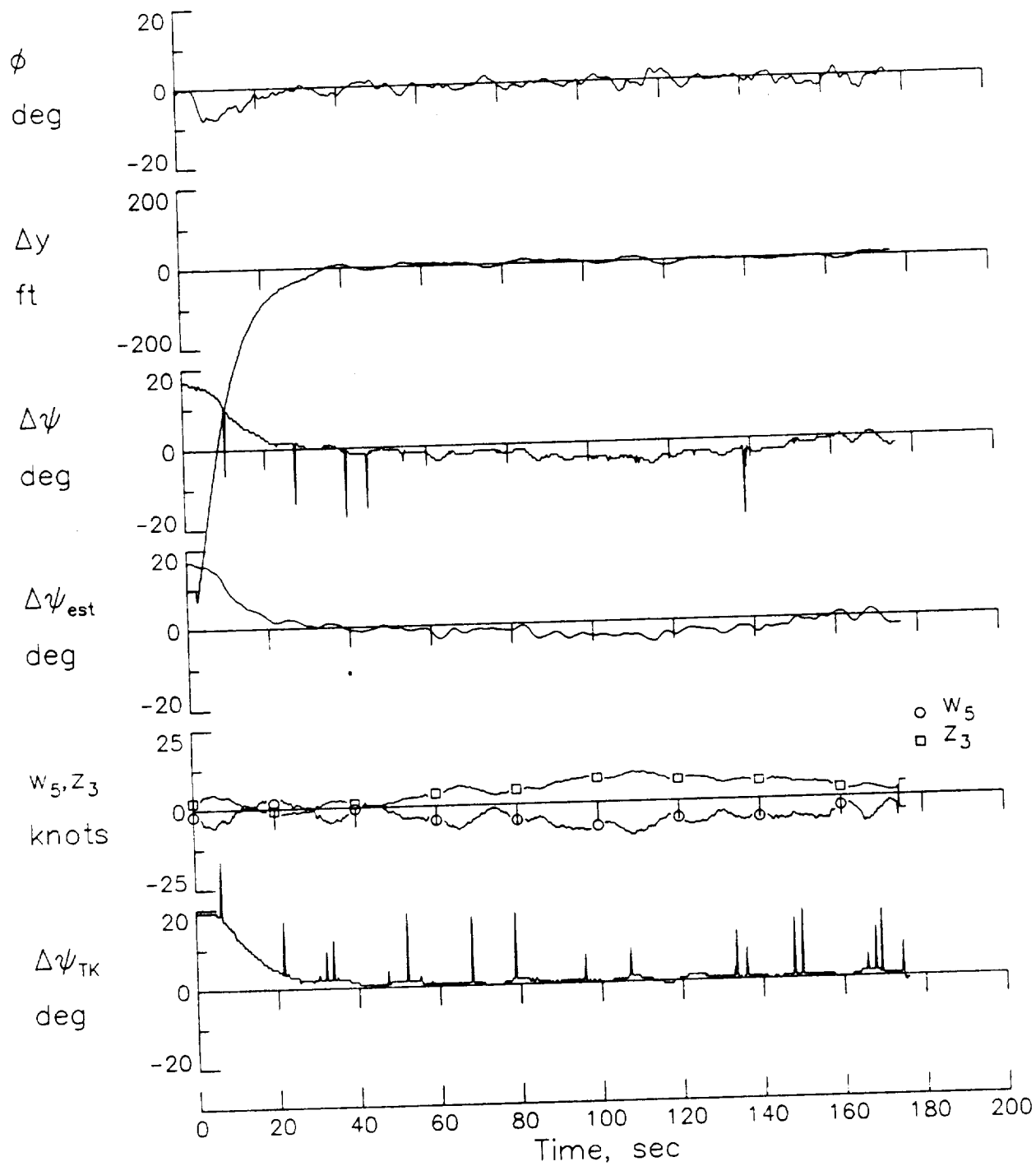


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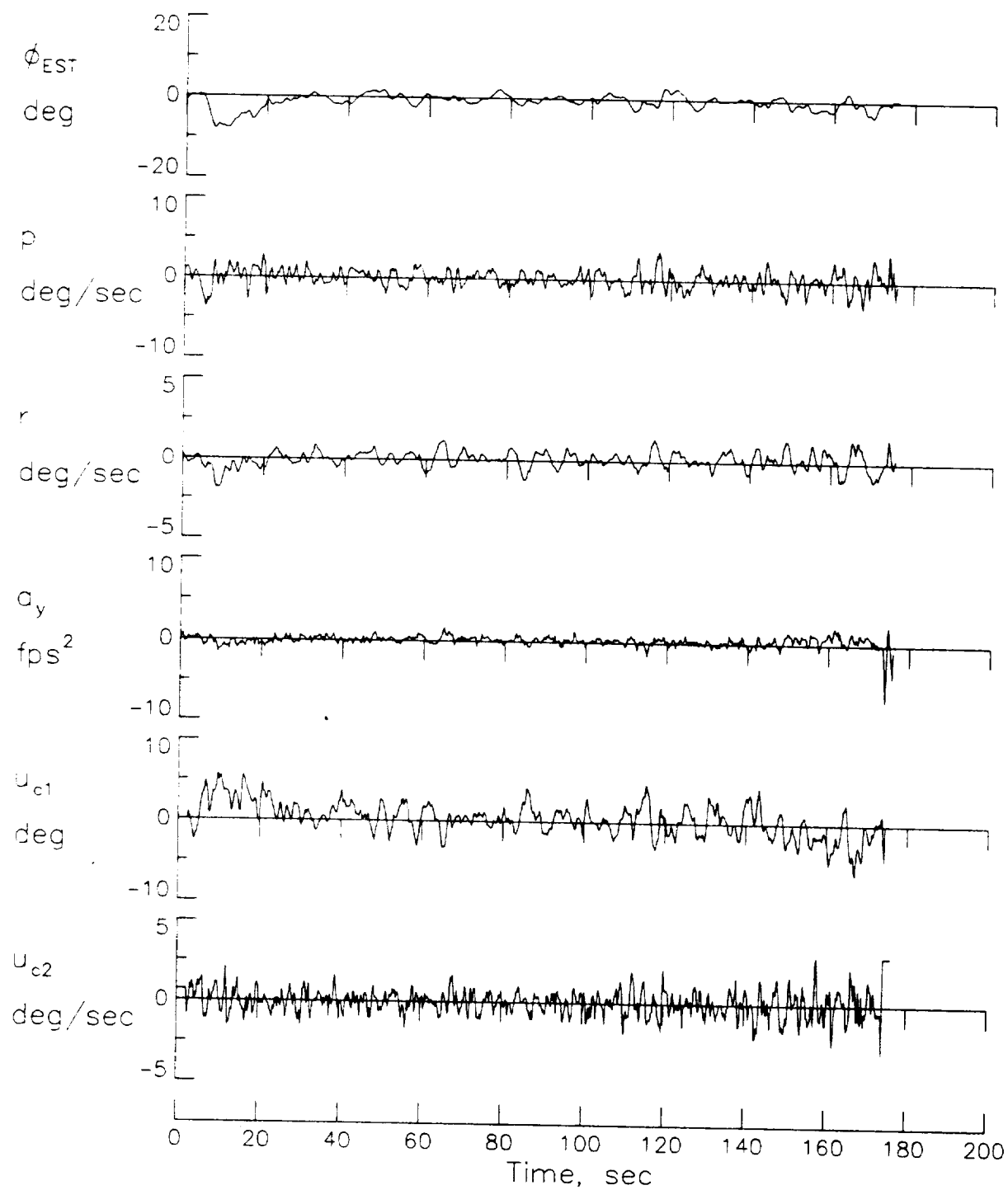


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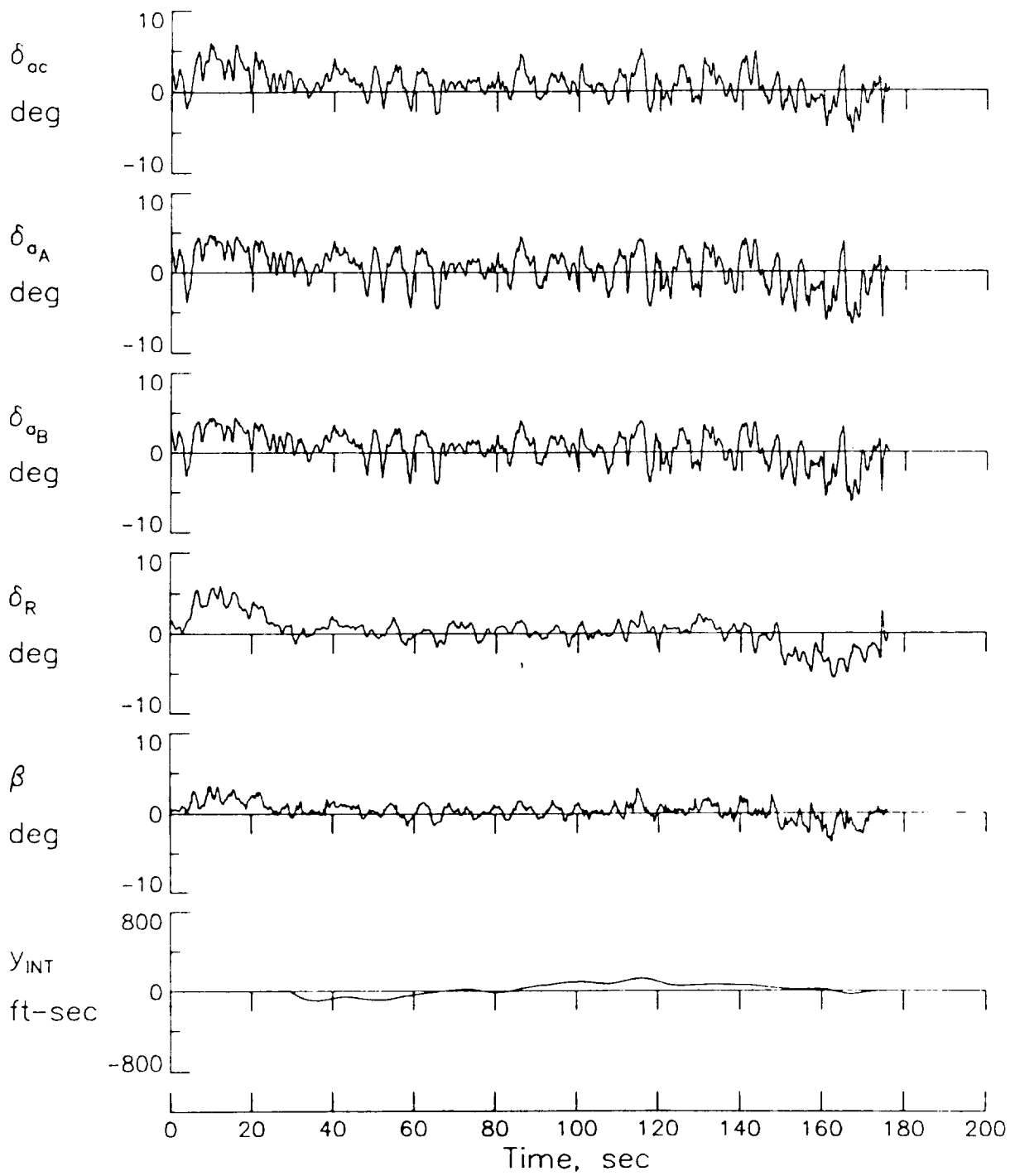


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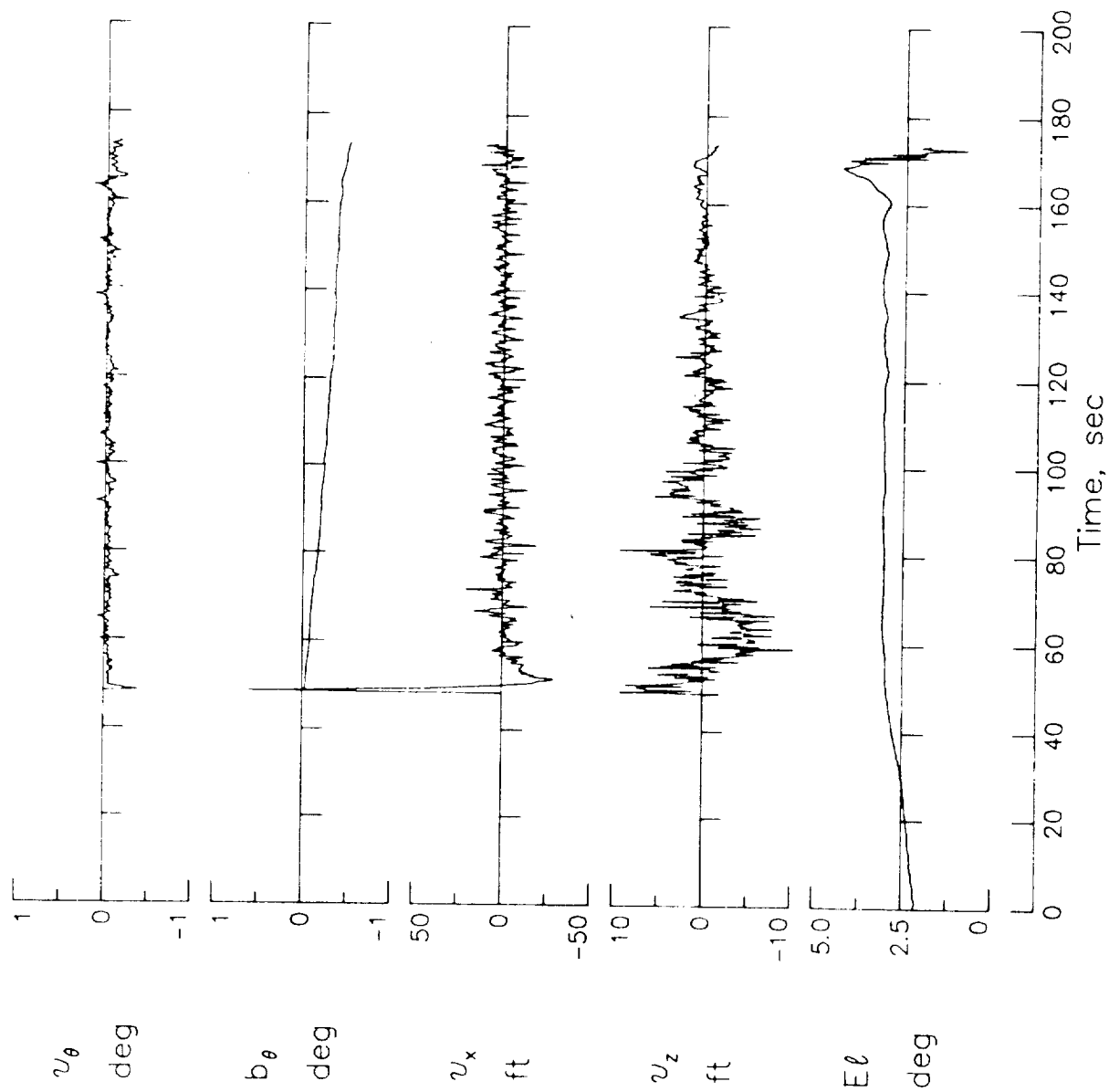


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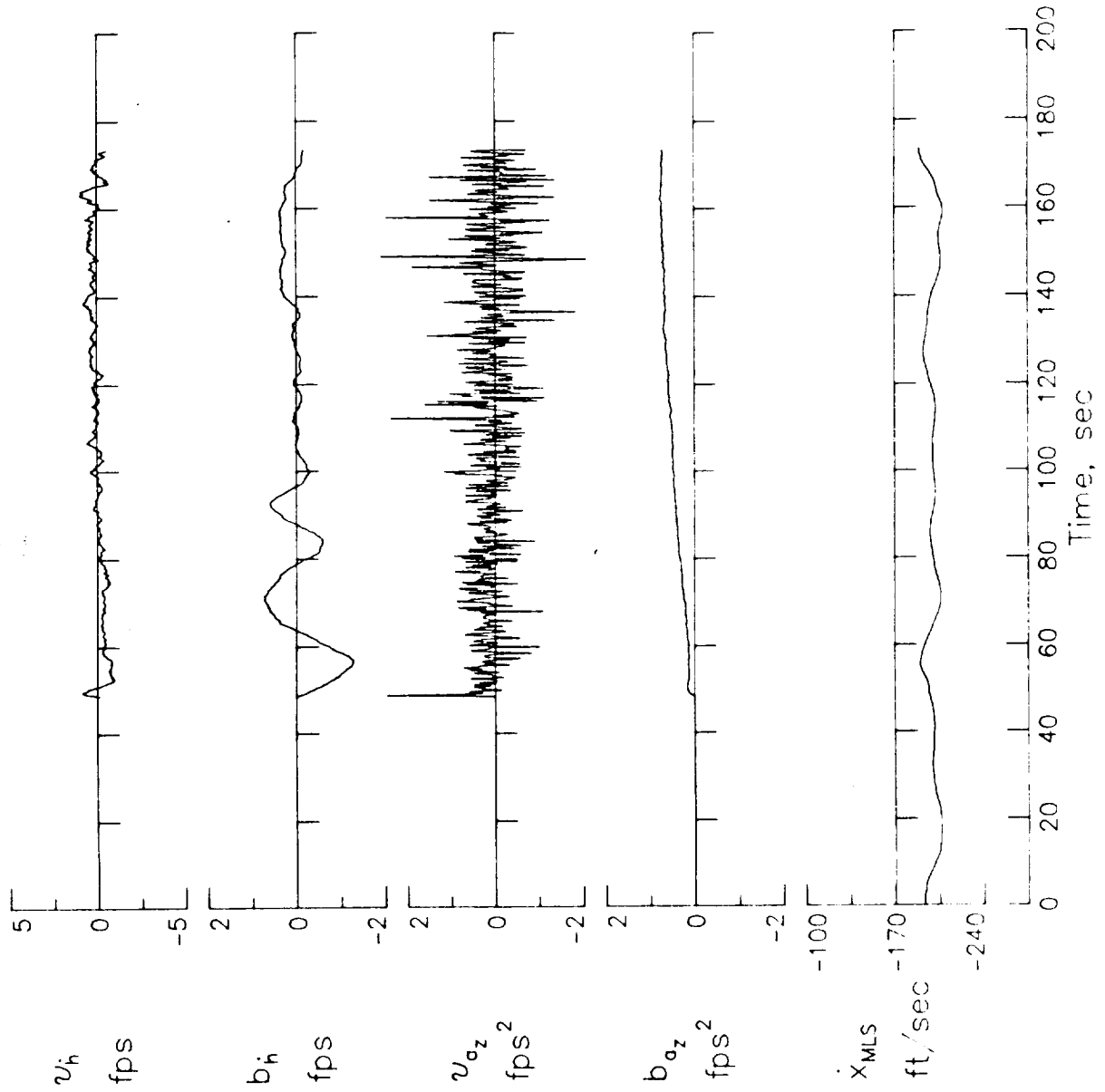


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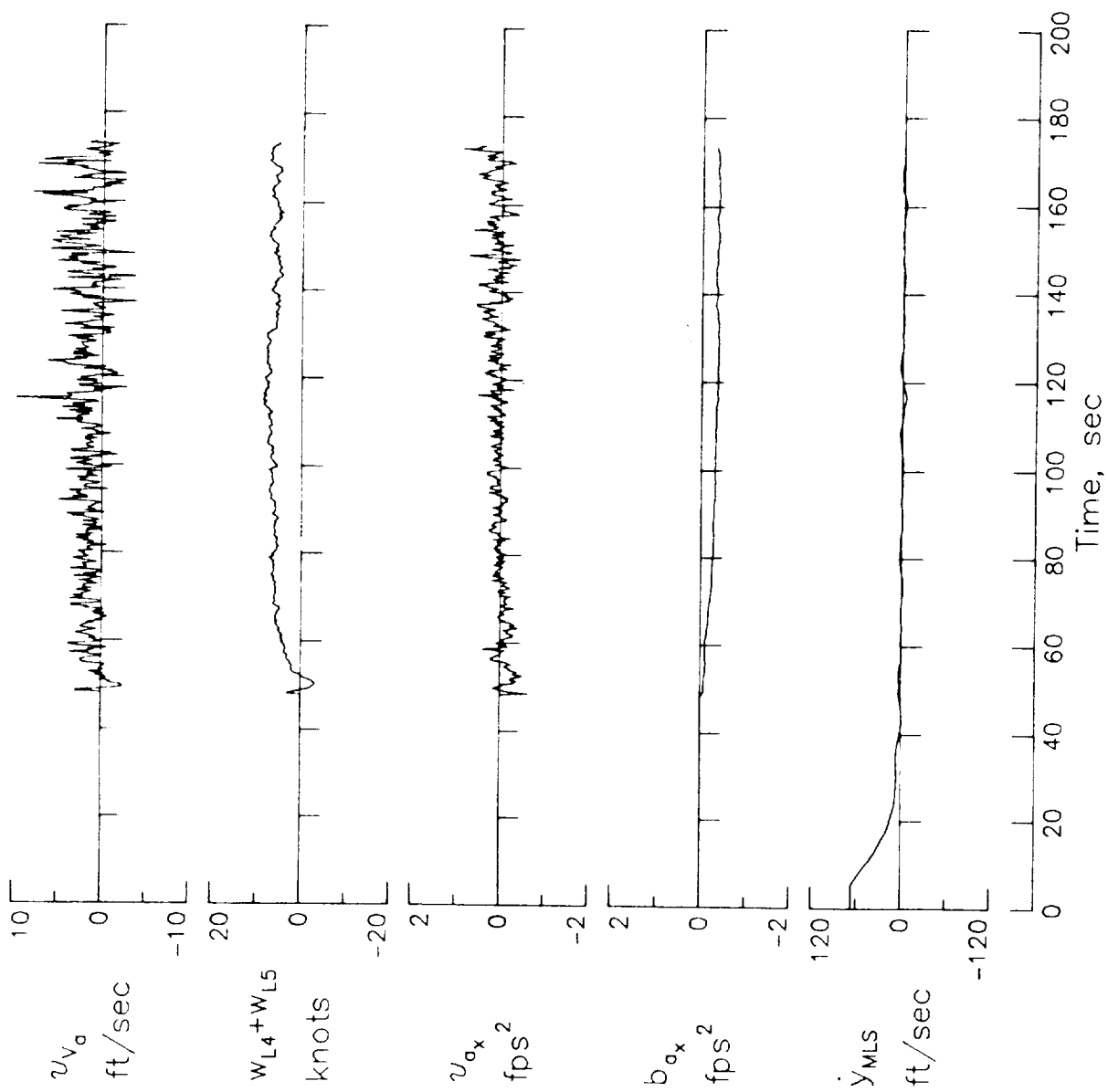


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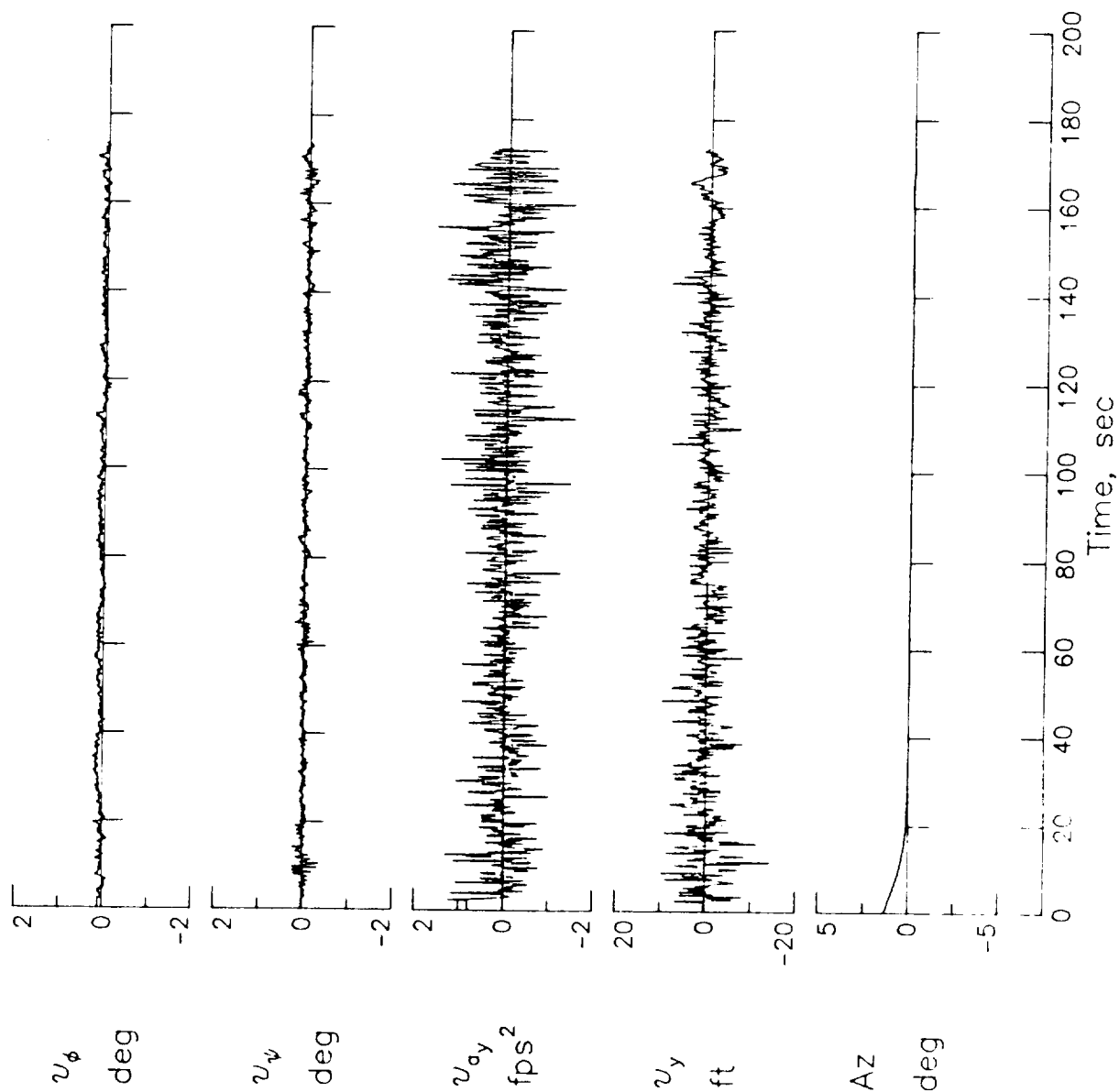


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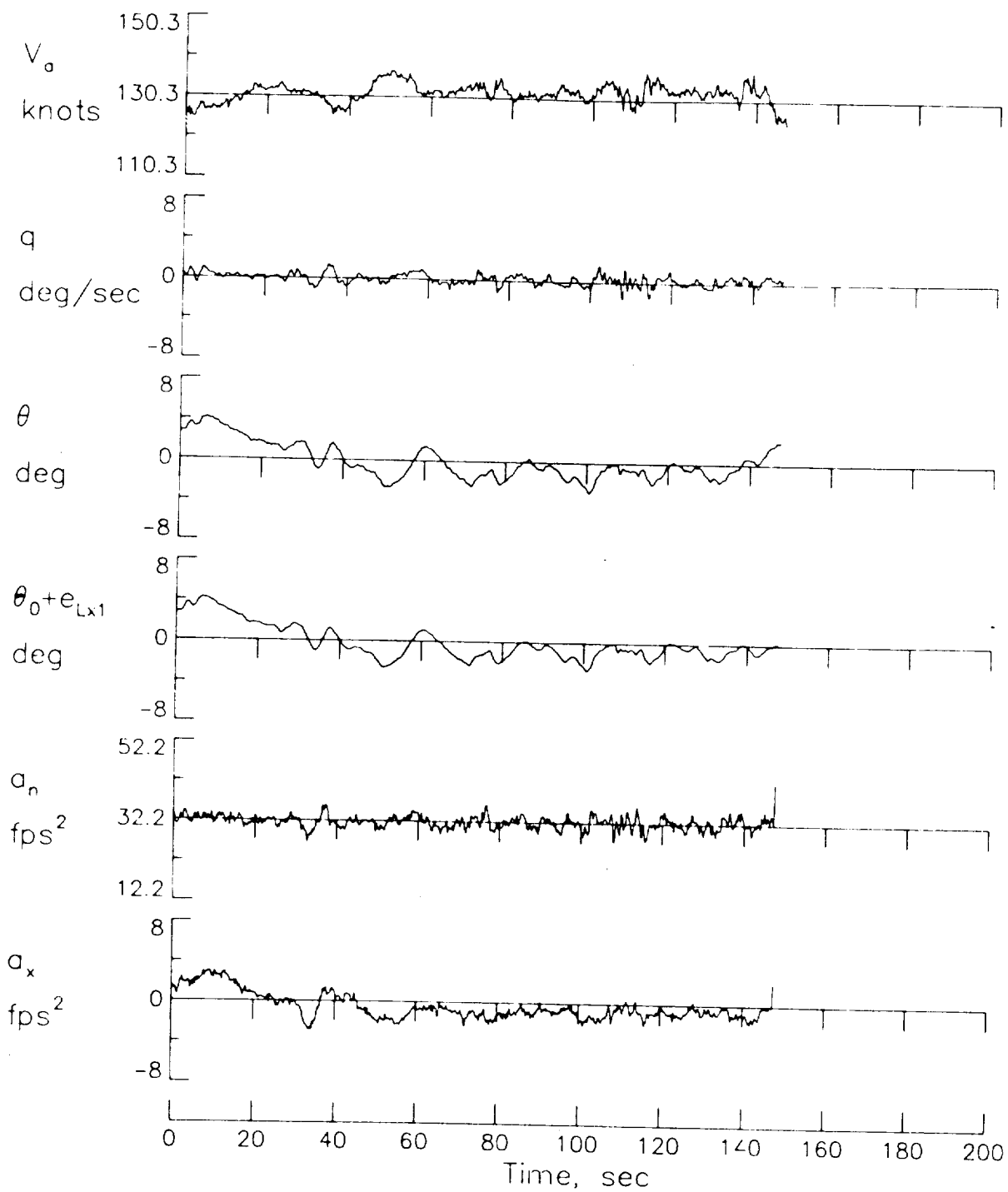


Figure 10. Flight Data for DIALS Flight Test
R355, Run 8

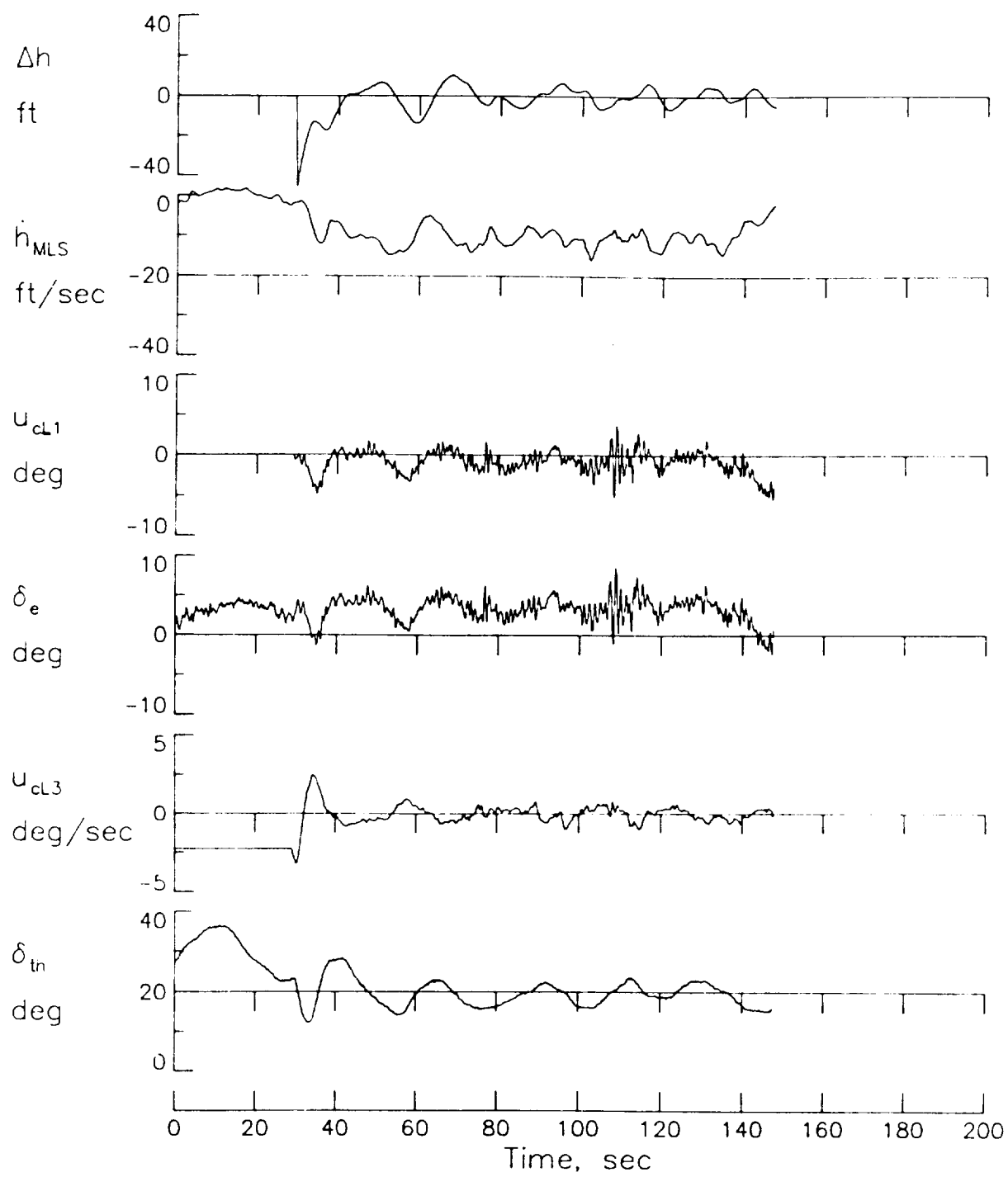


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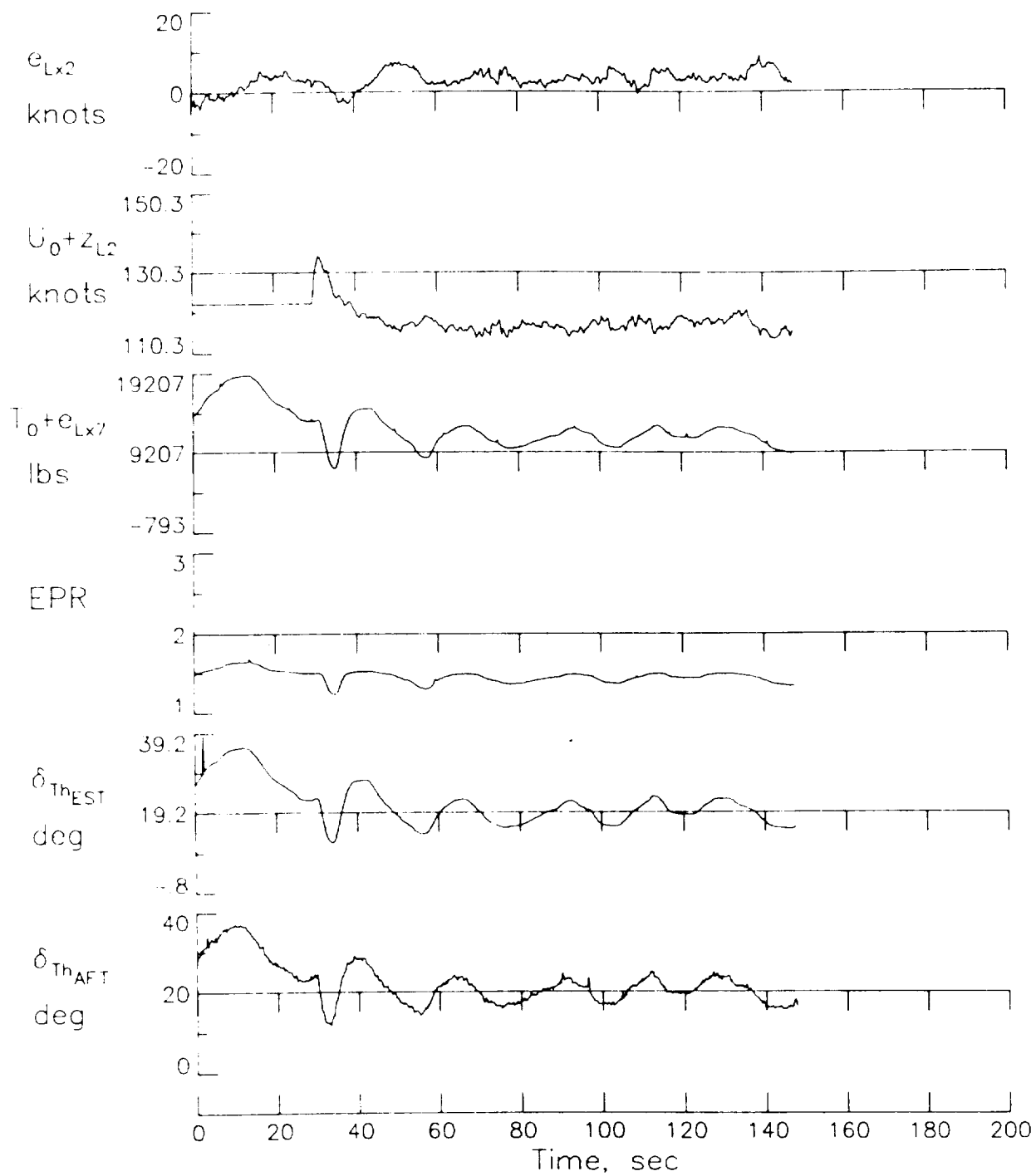


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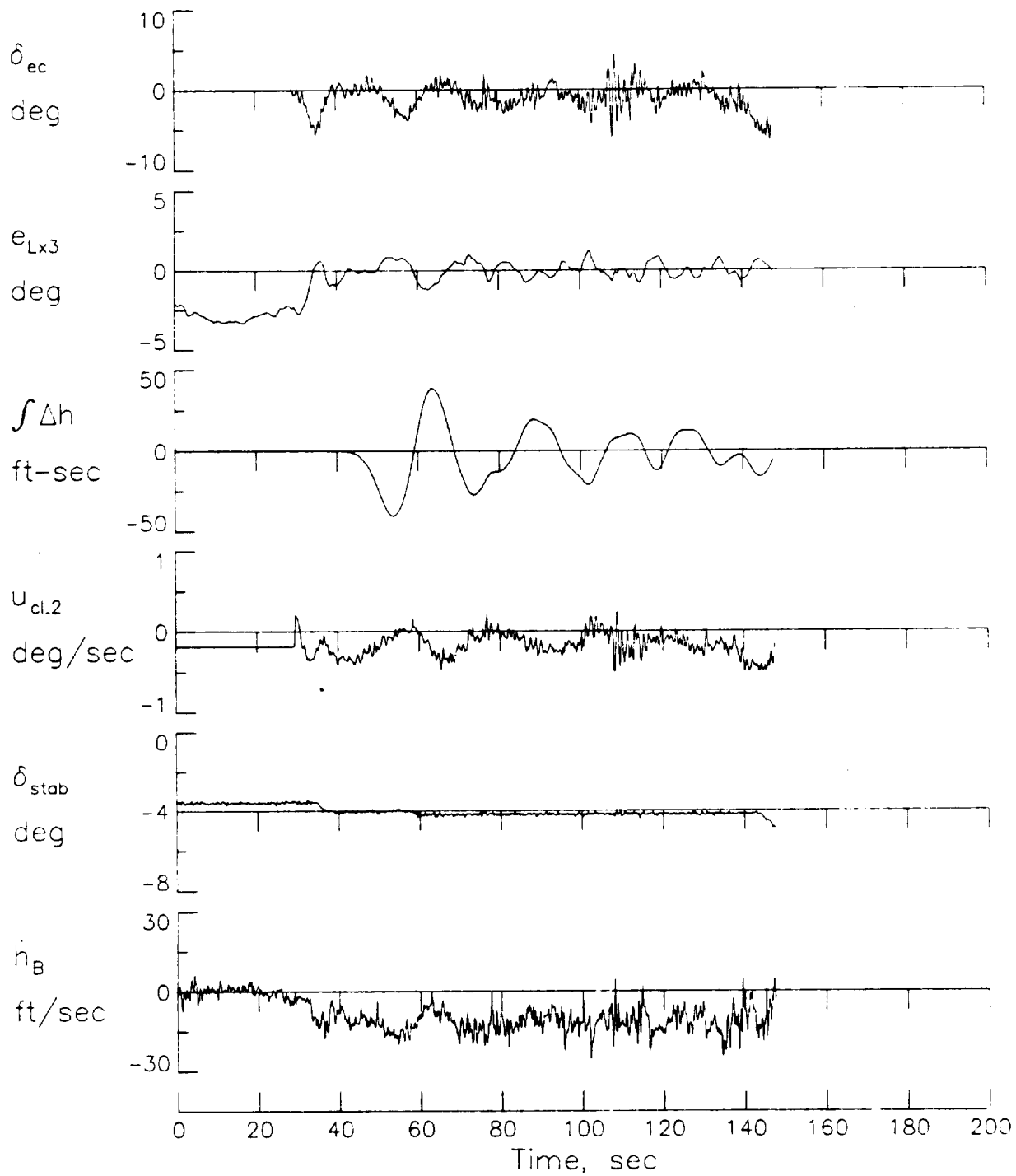


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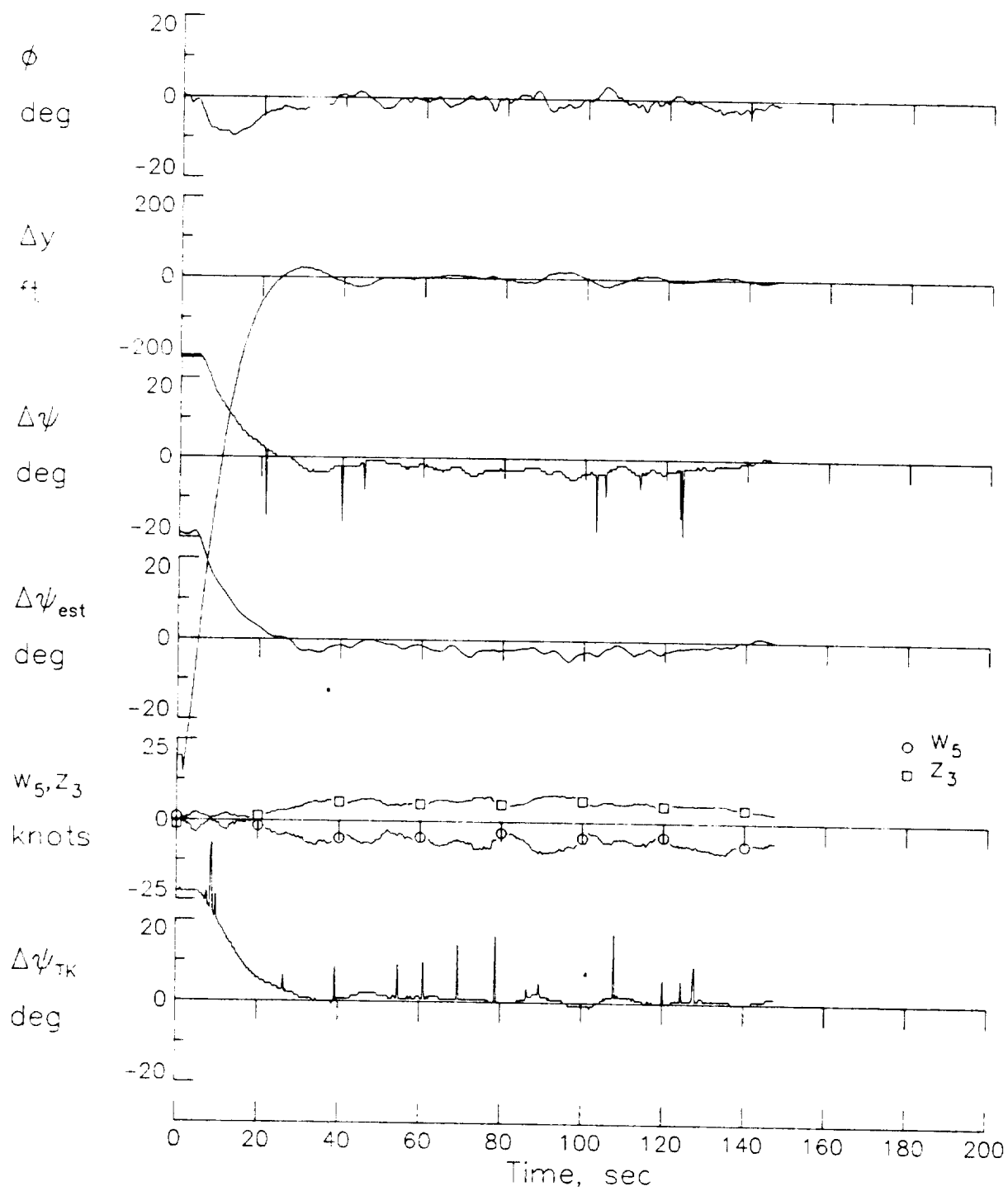


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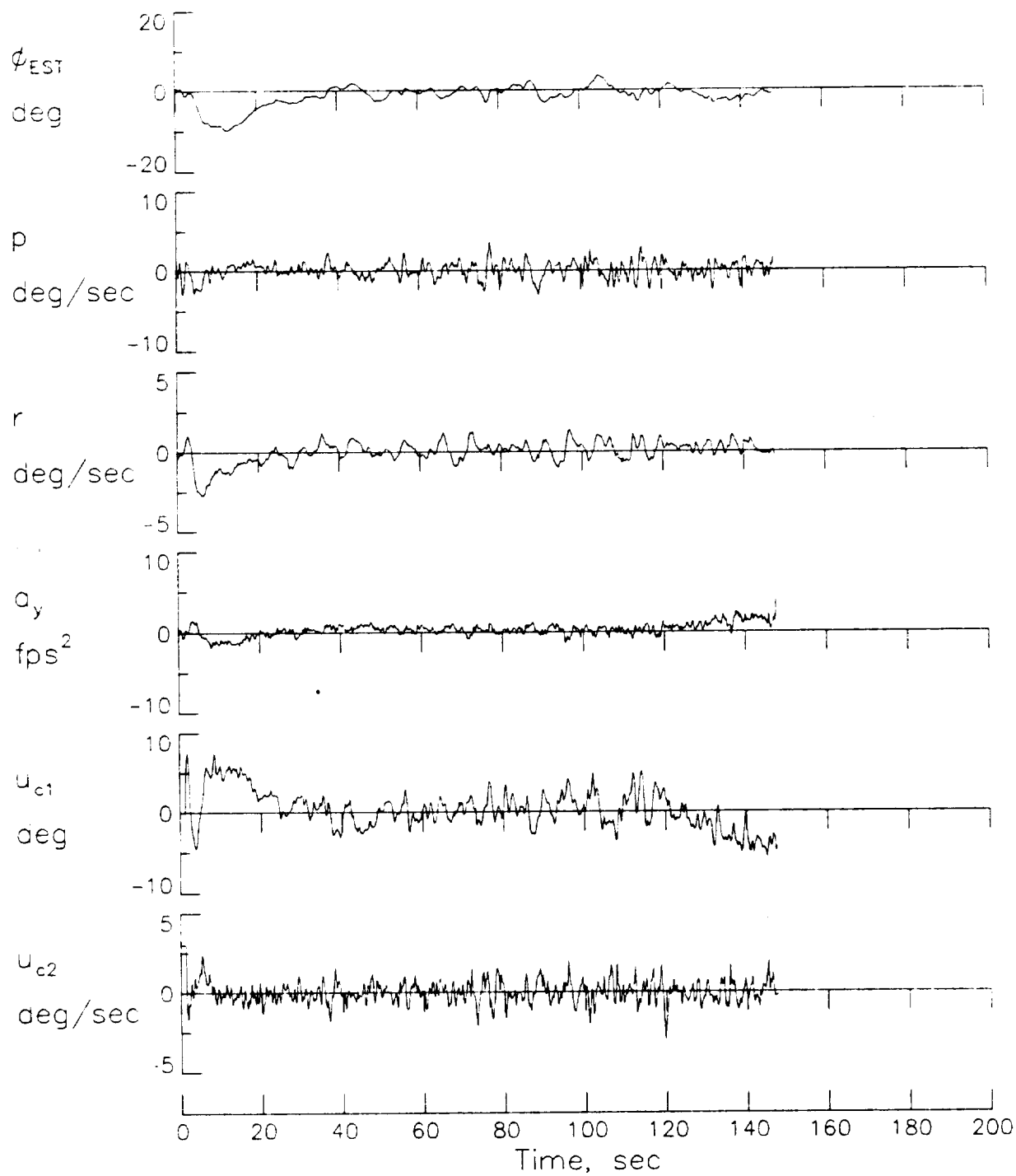


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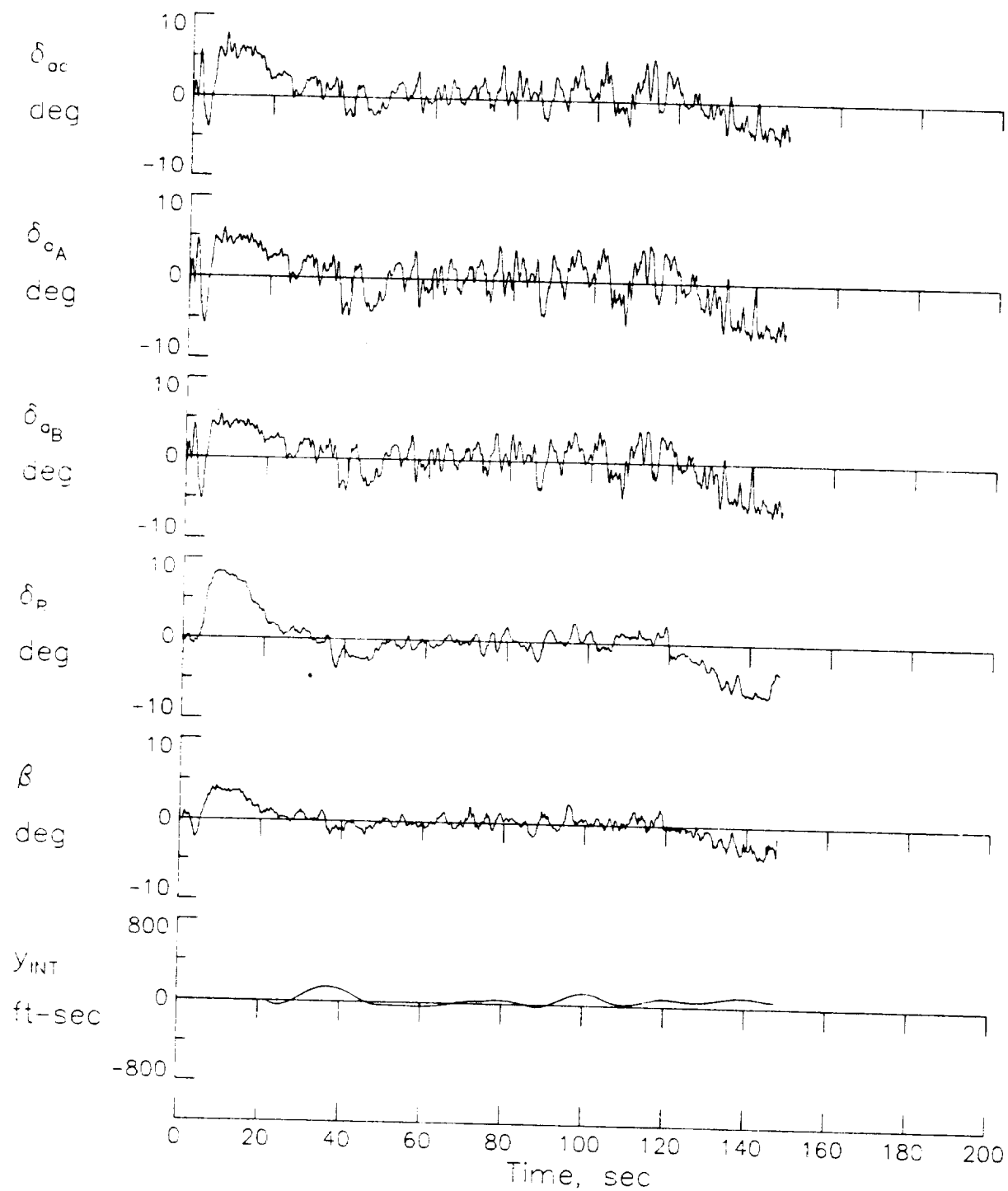


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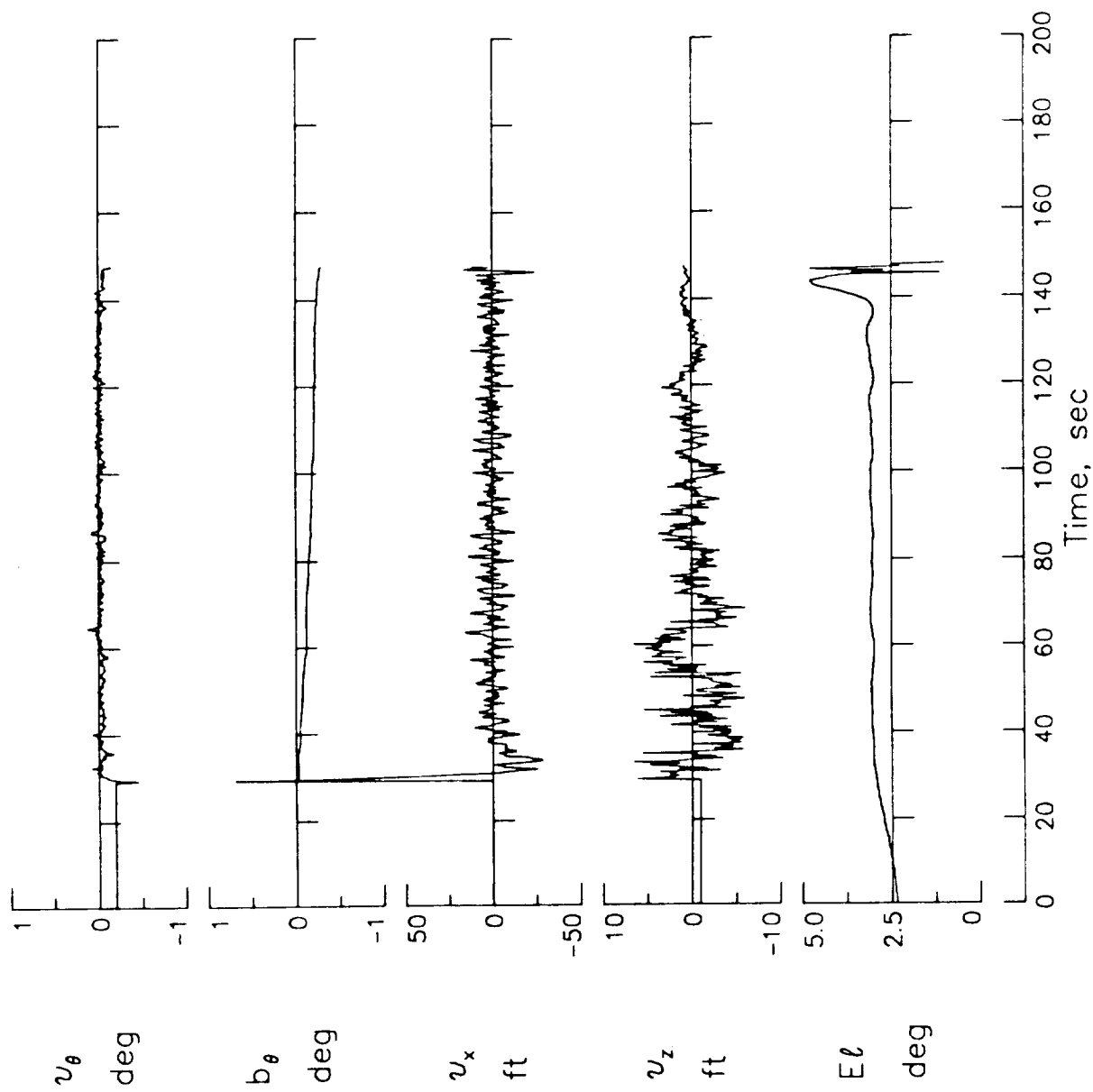


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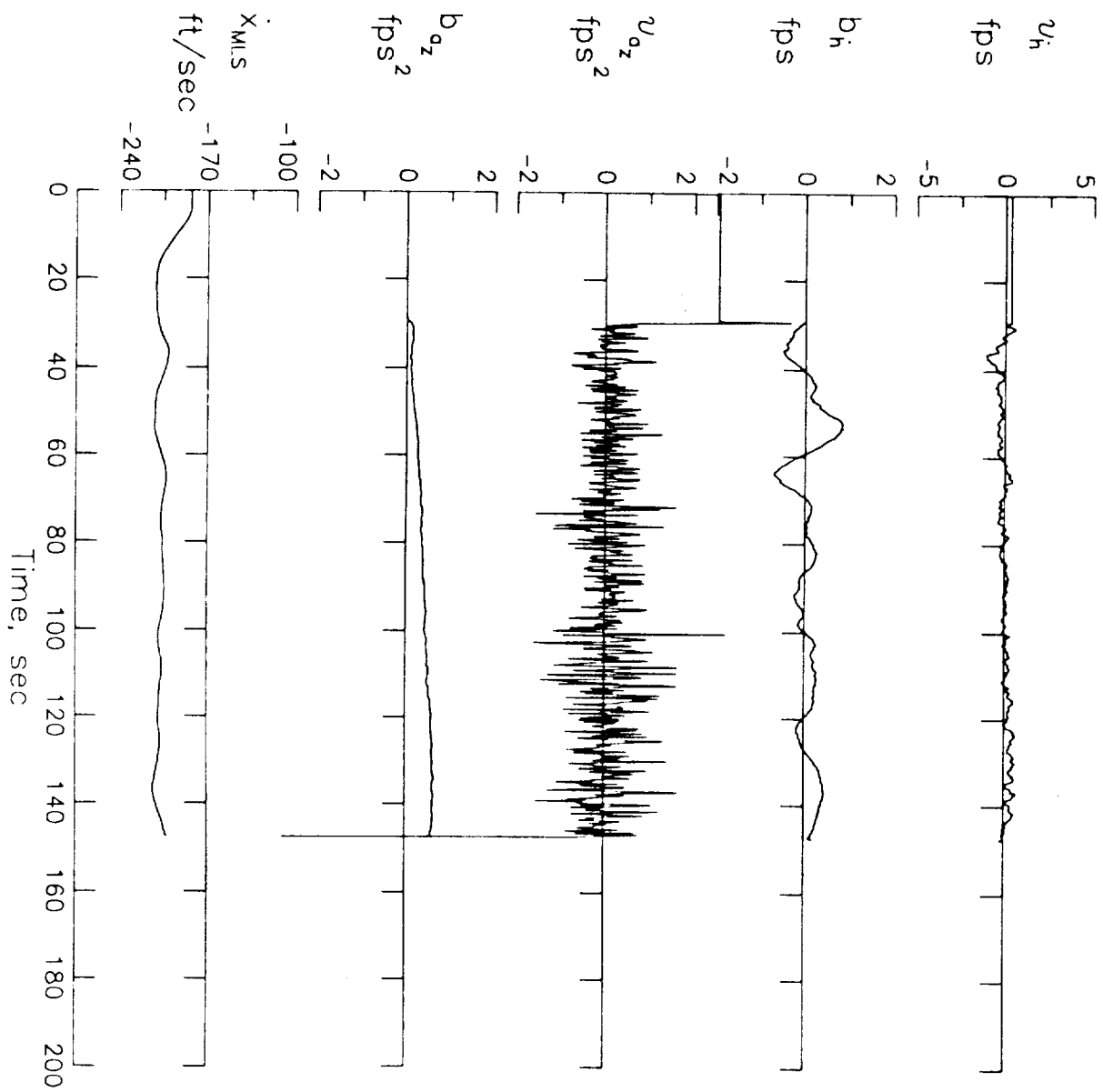


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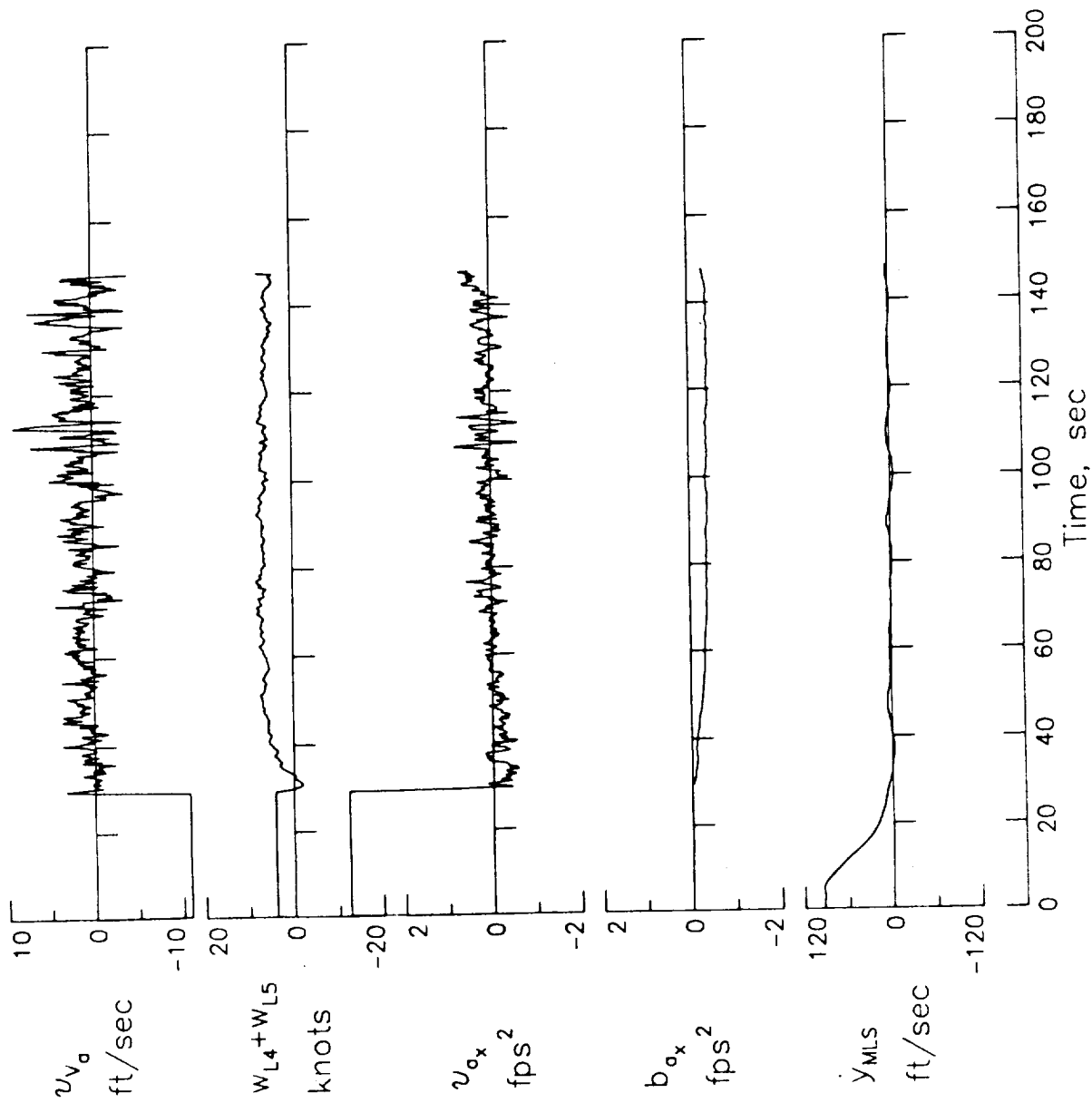


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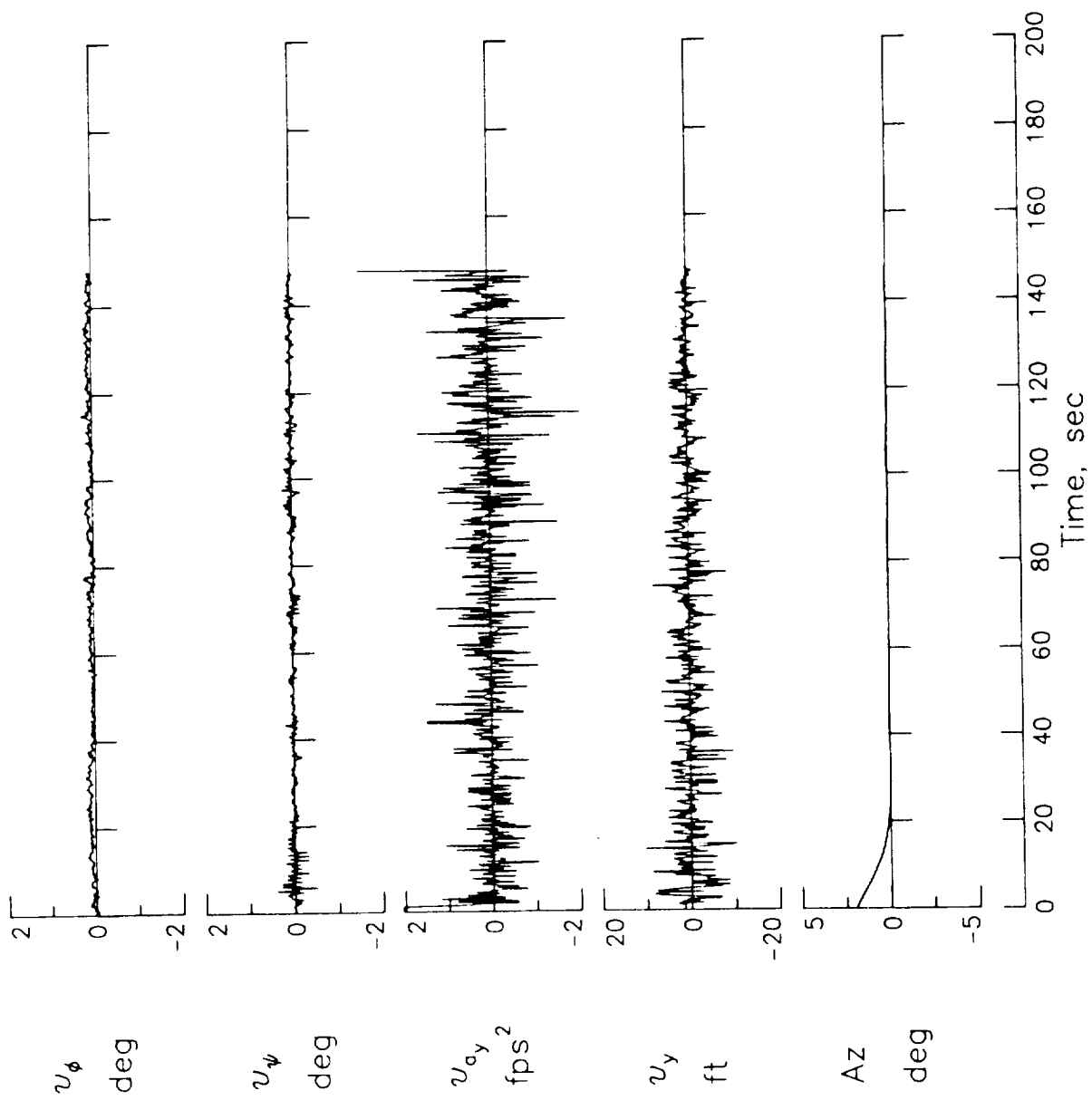


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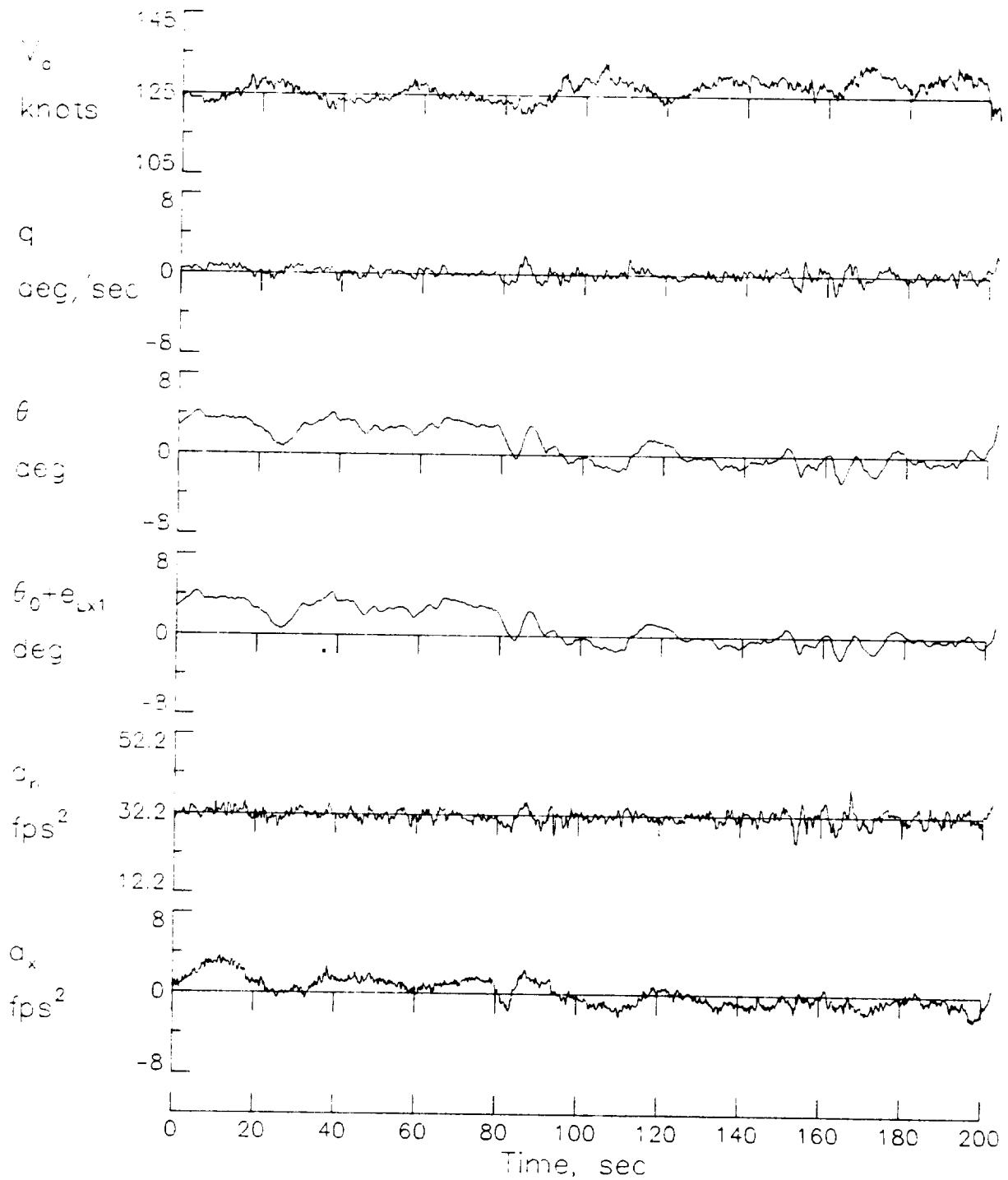


Figure 11. Flight Data for DIALS Flight Test
R355, Run 9

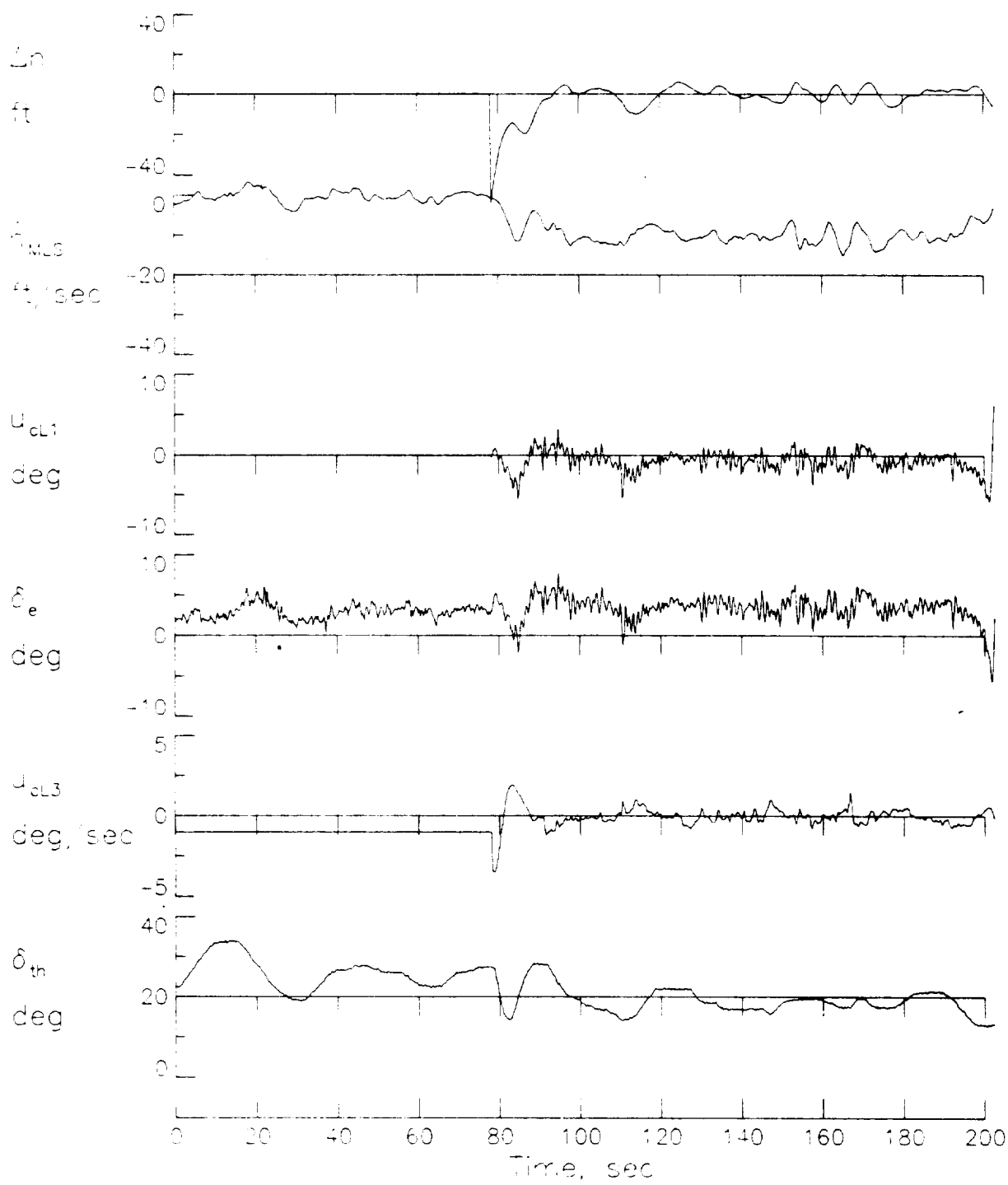


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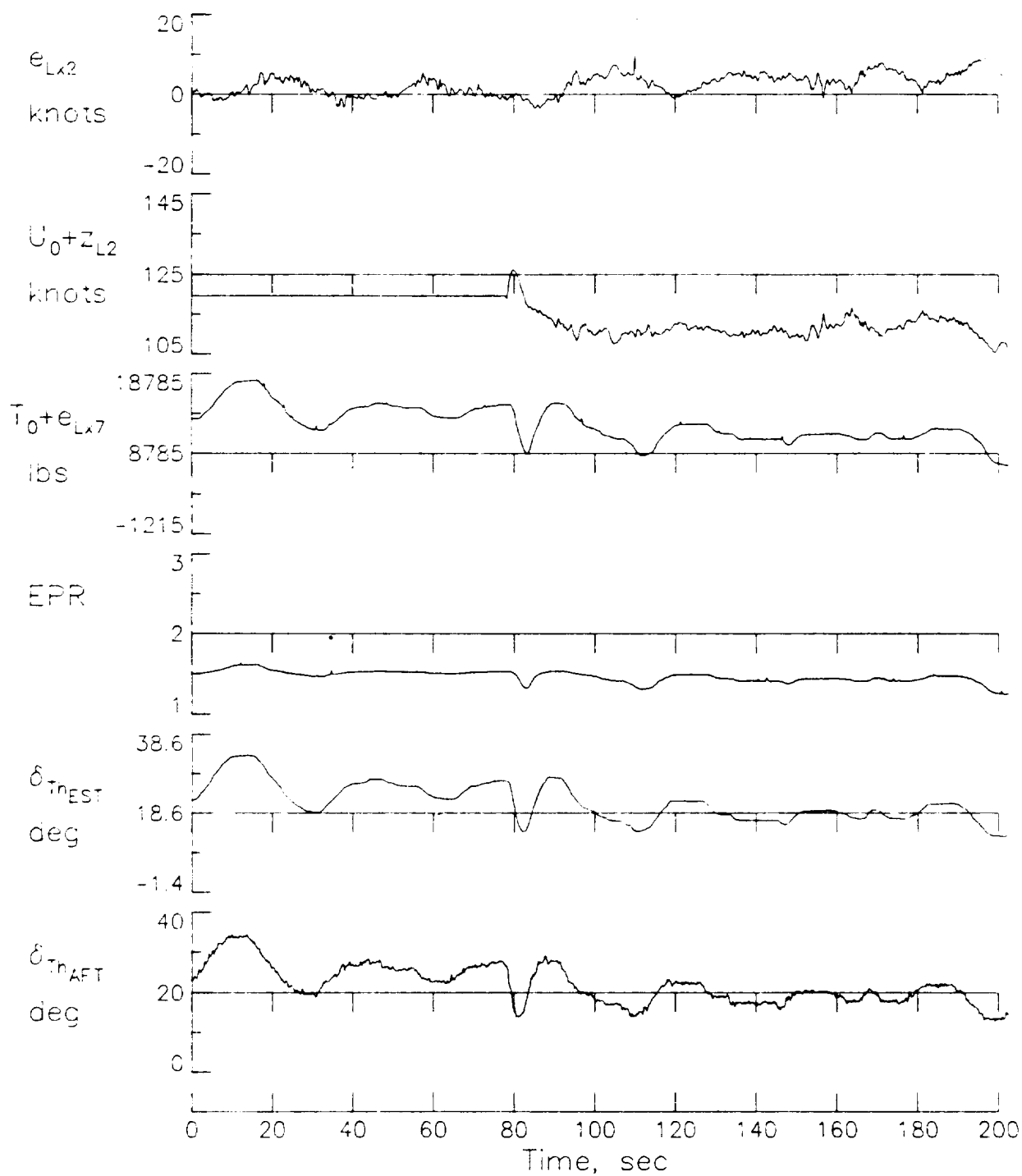


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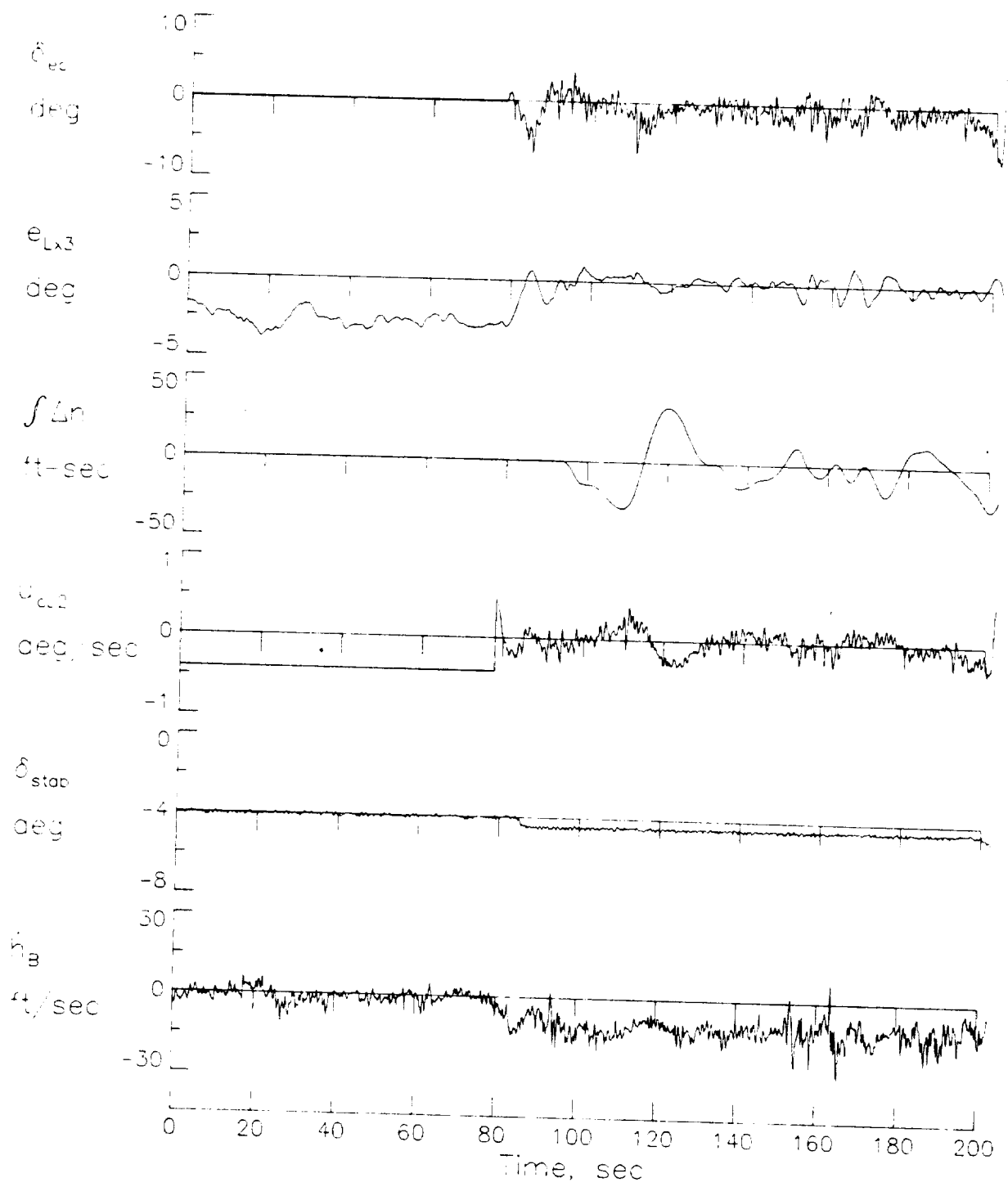


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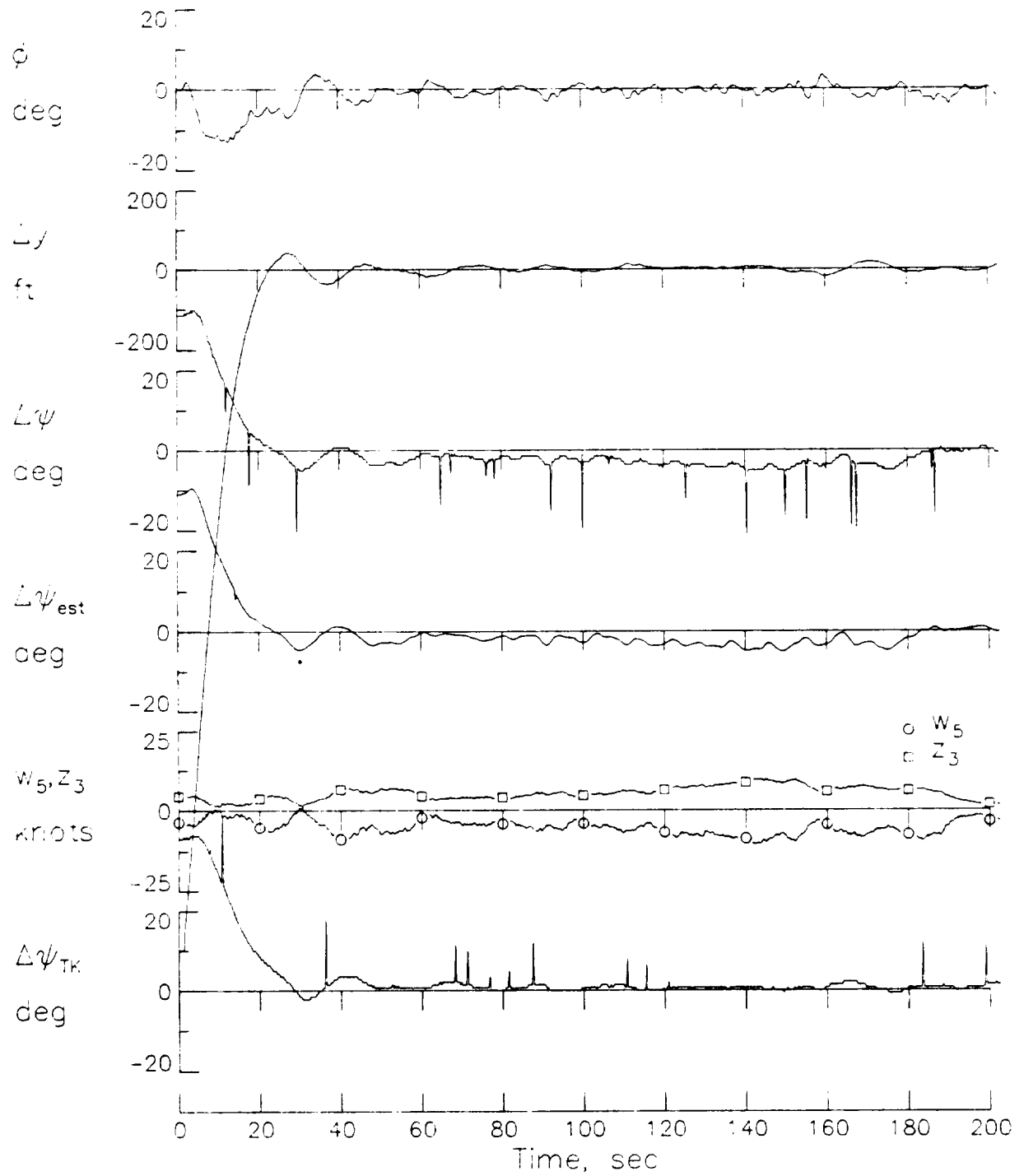


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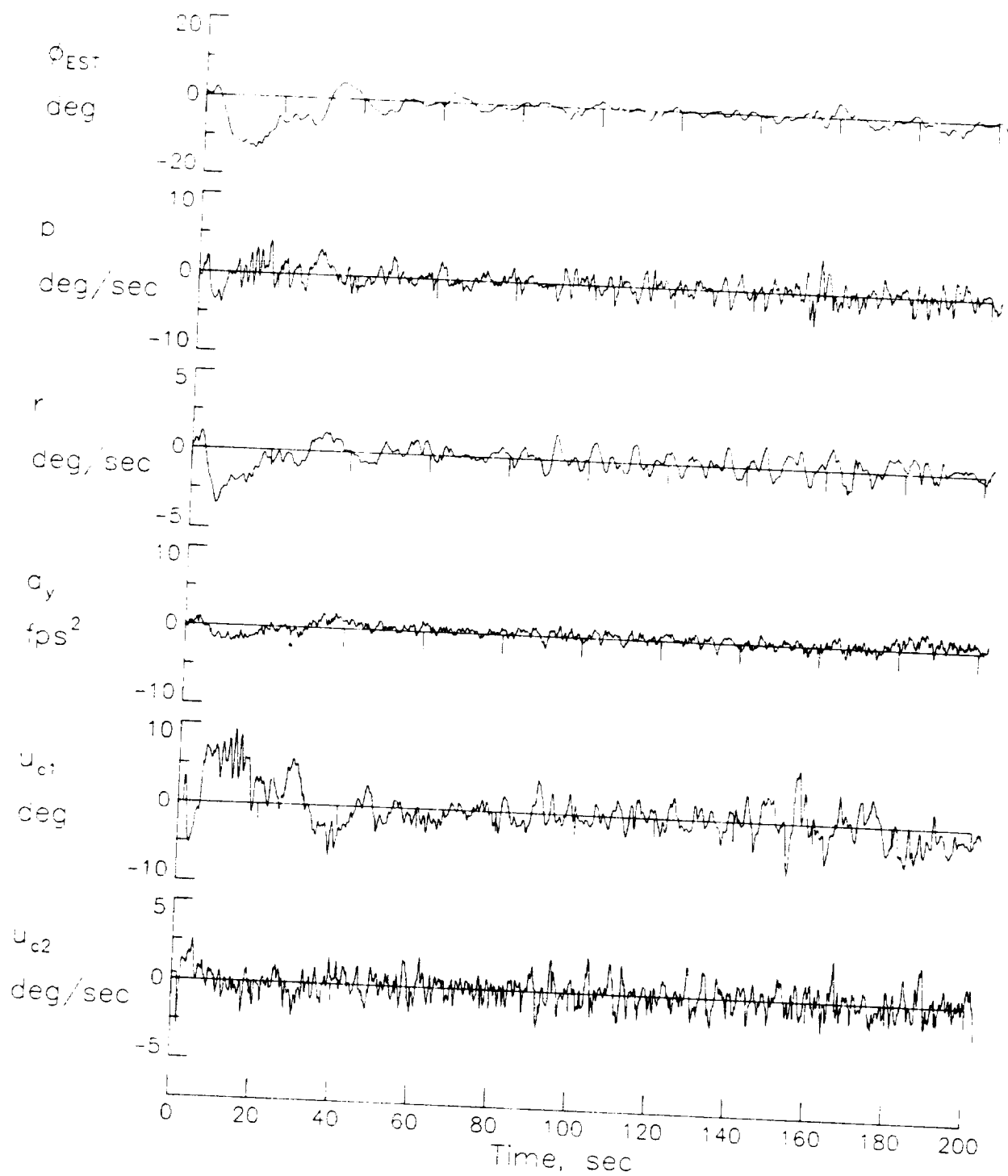


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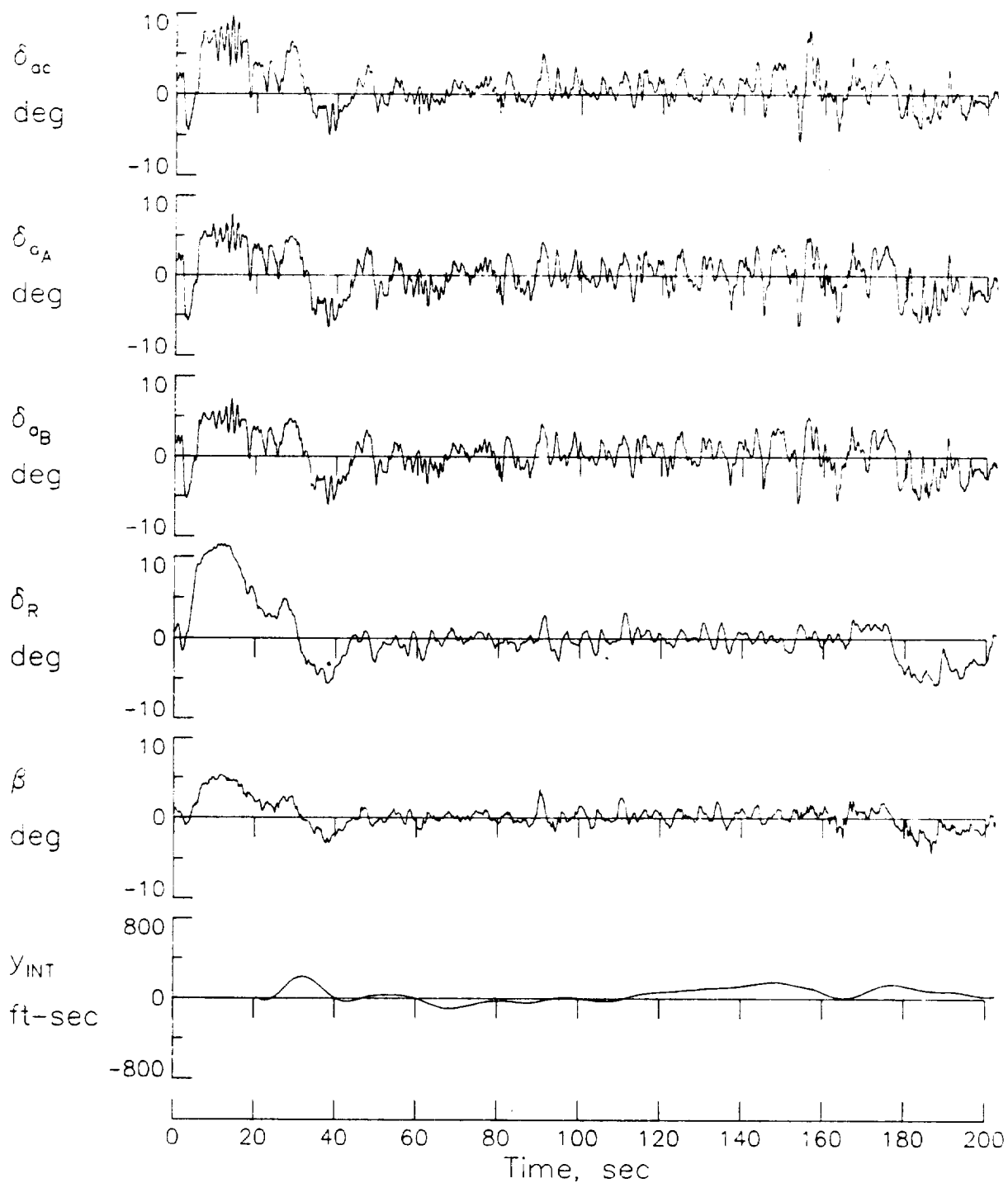


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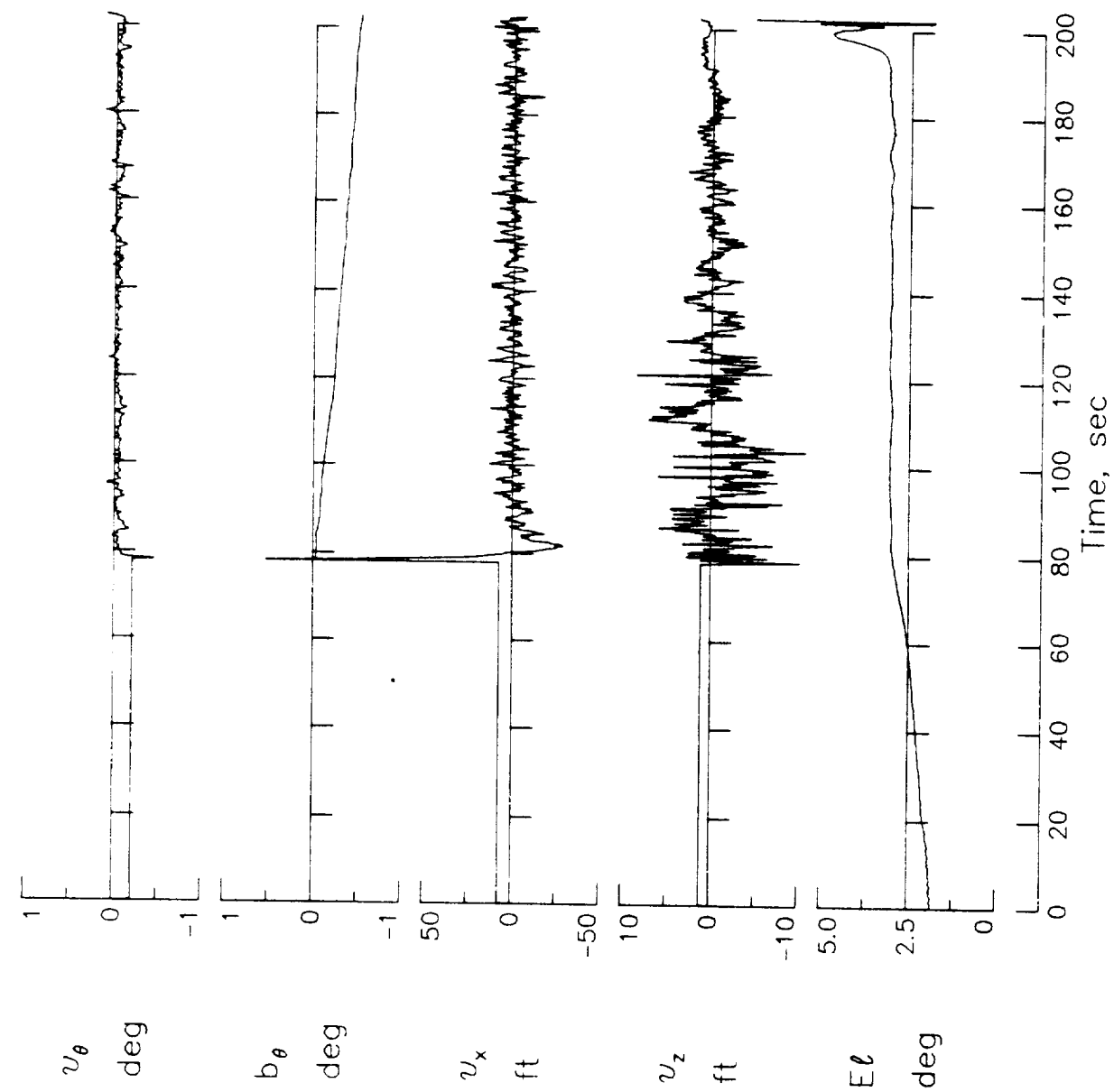


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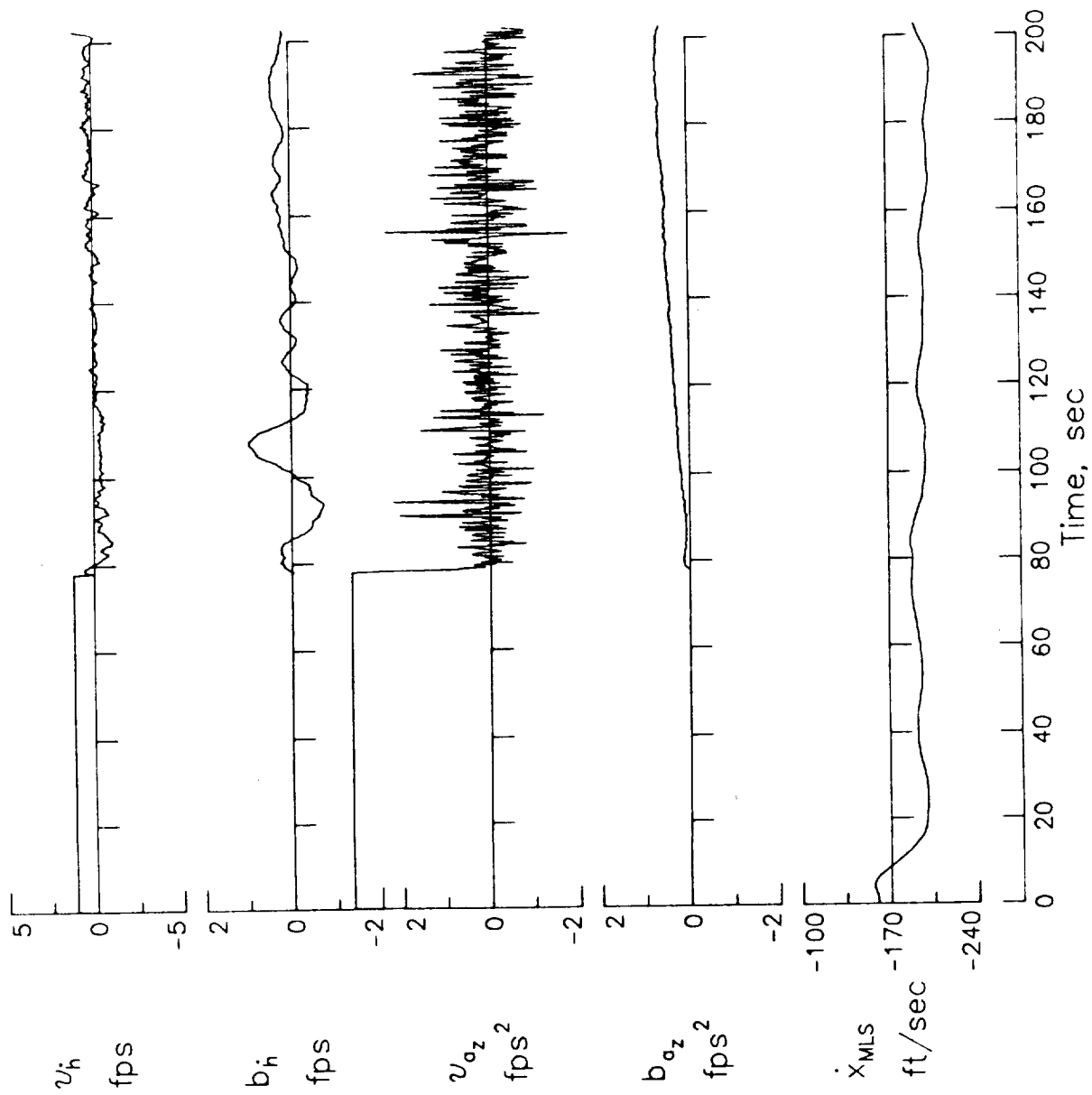


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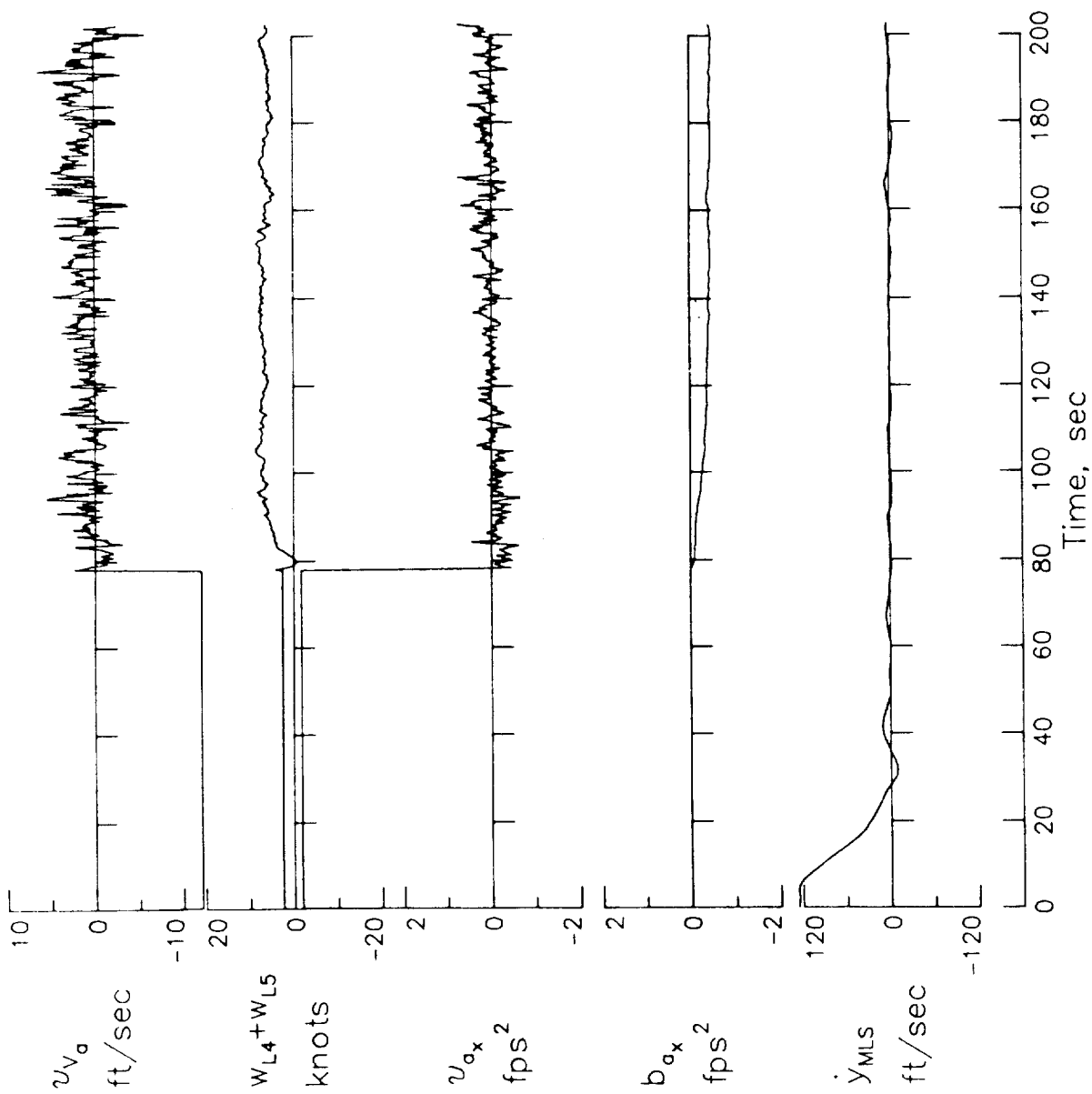


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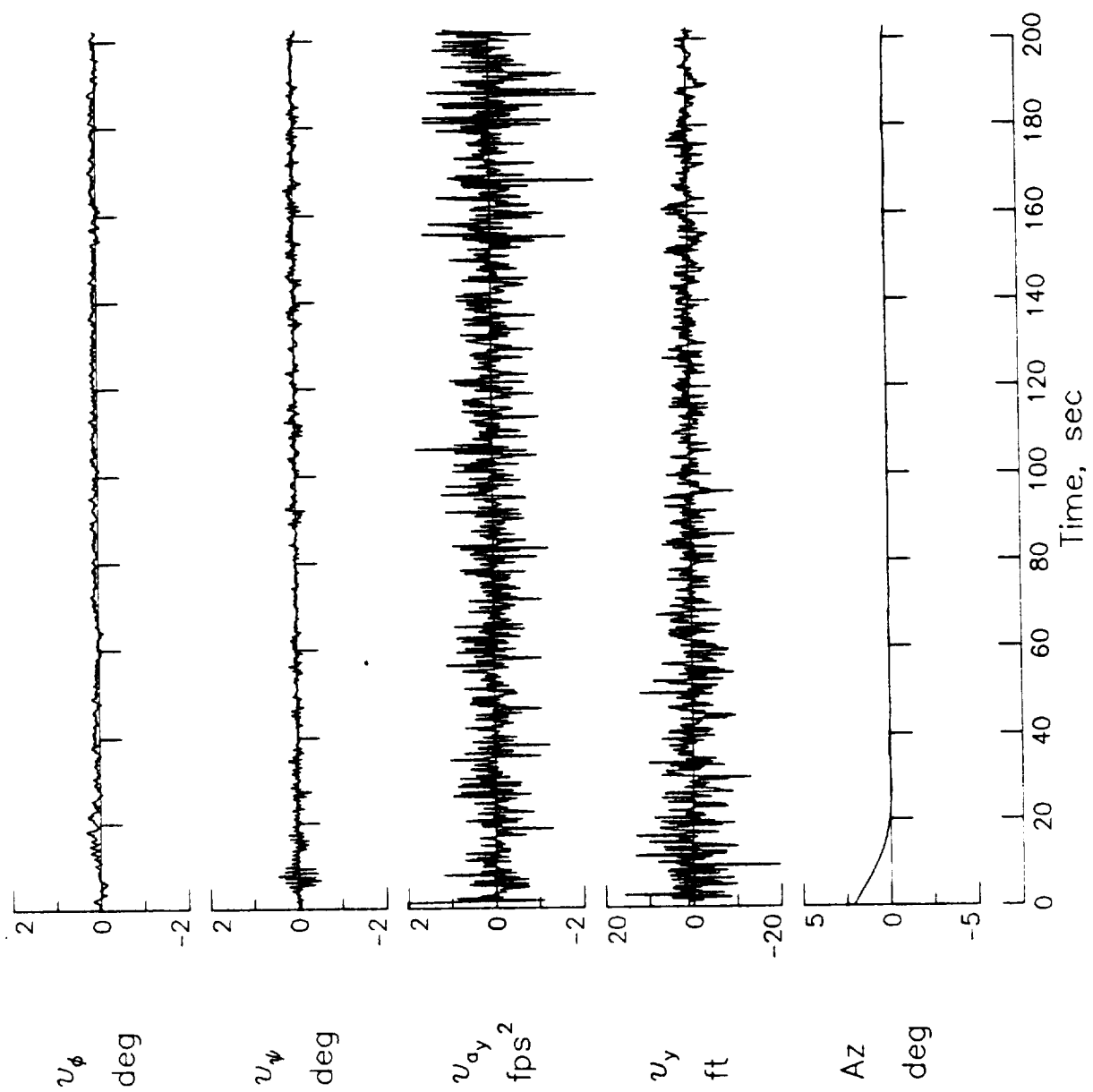


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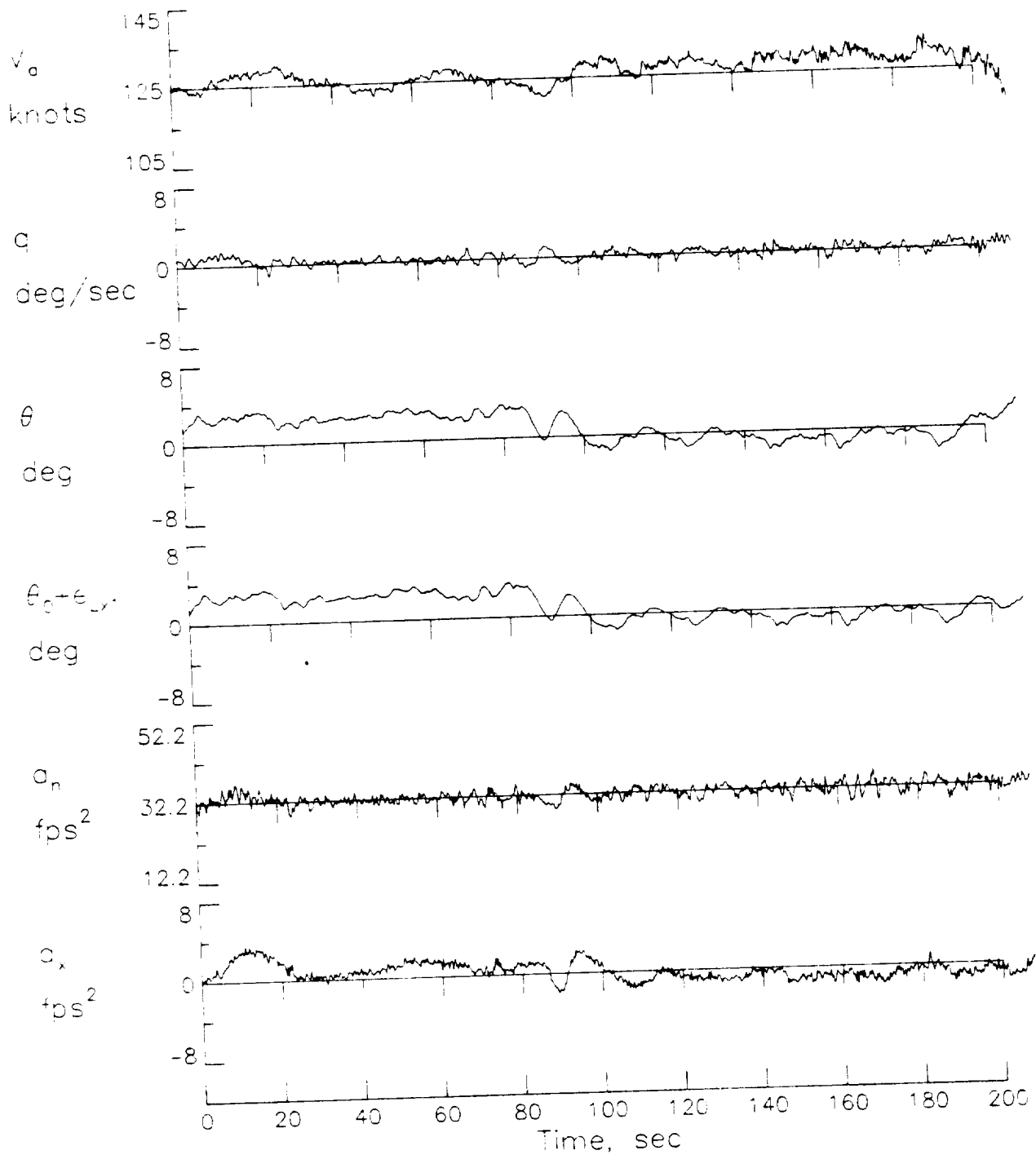


Figure 12. Flight Data for DIALS Flight Test
R355, Run 10

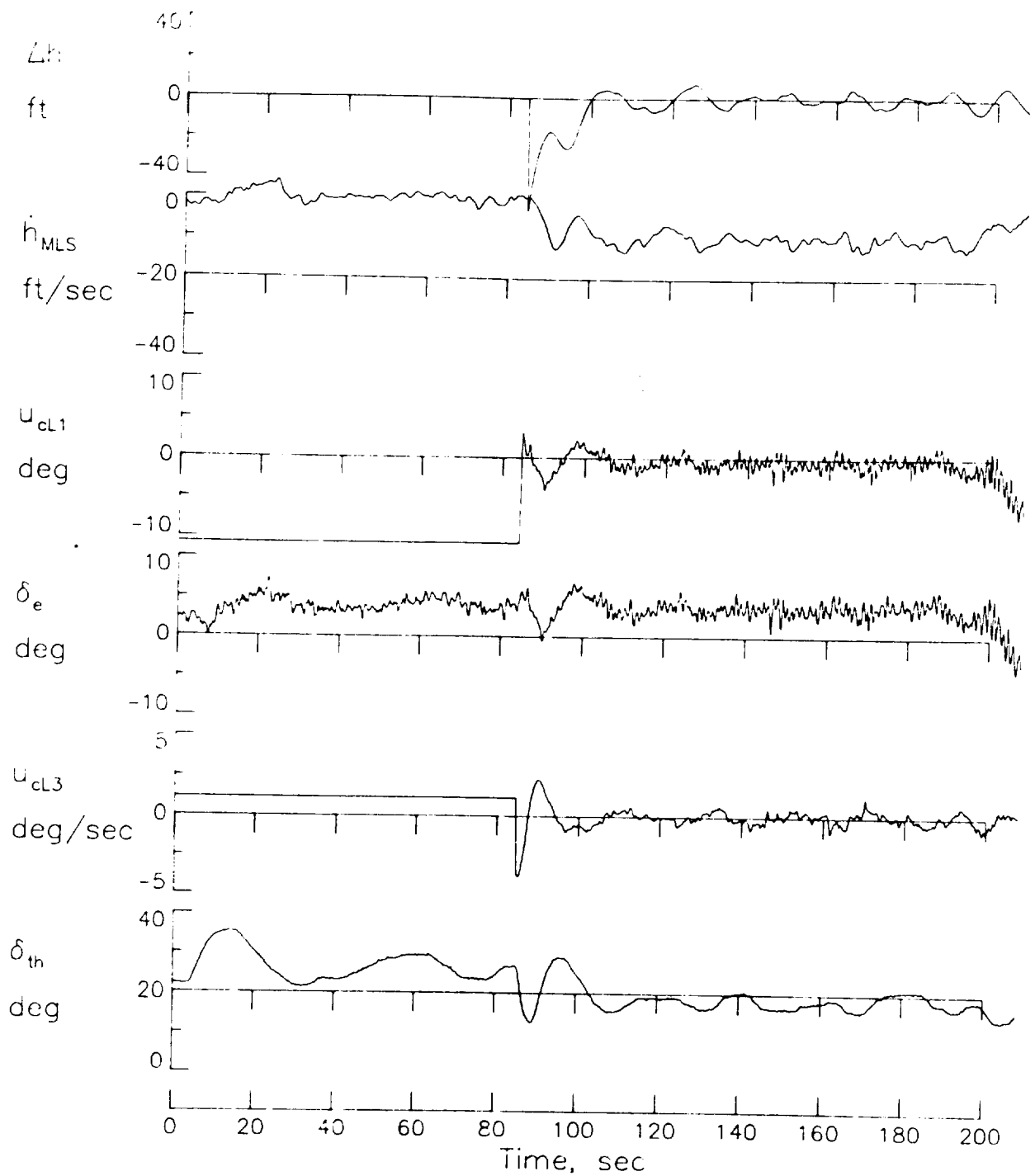


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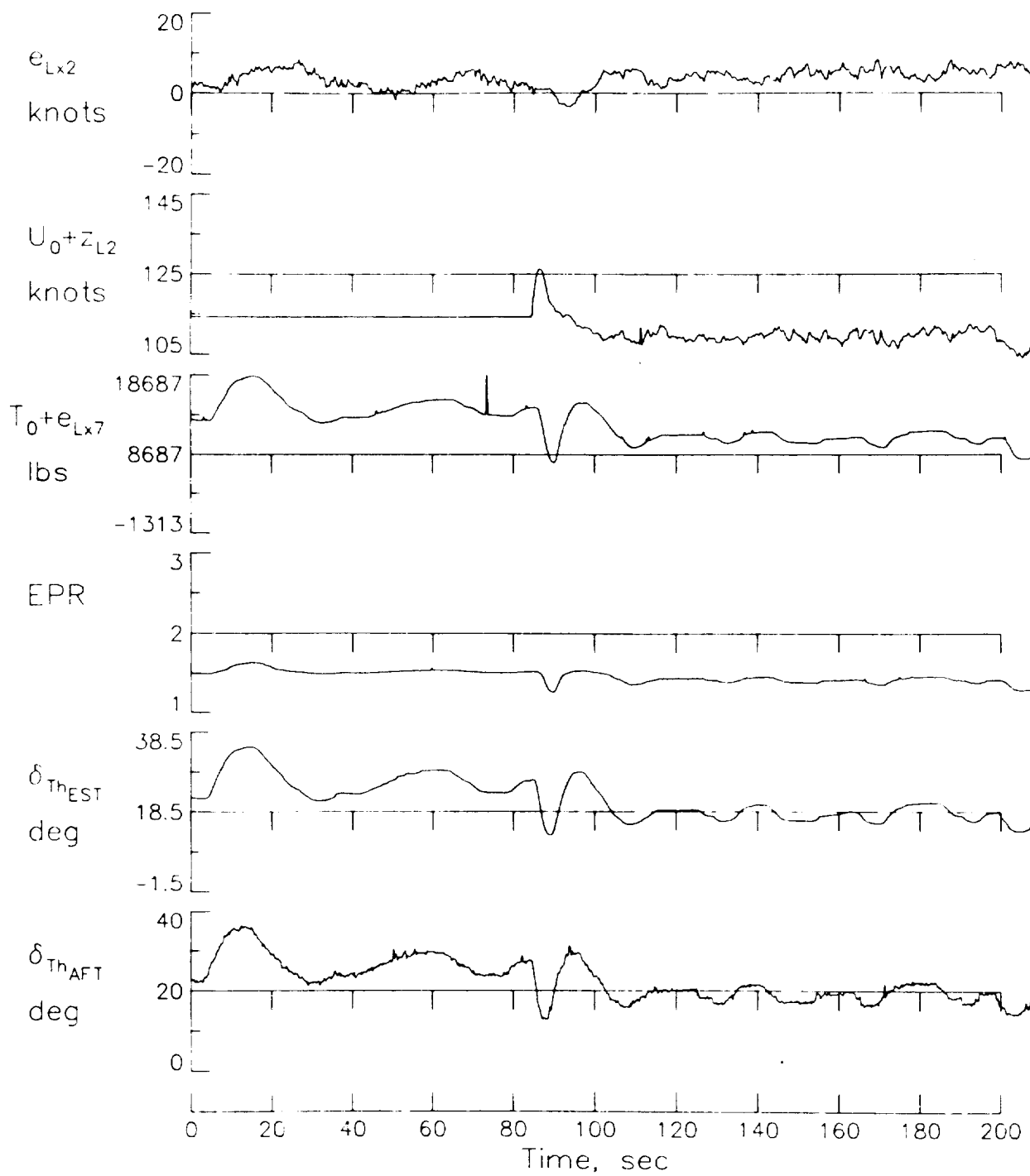


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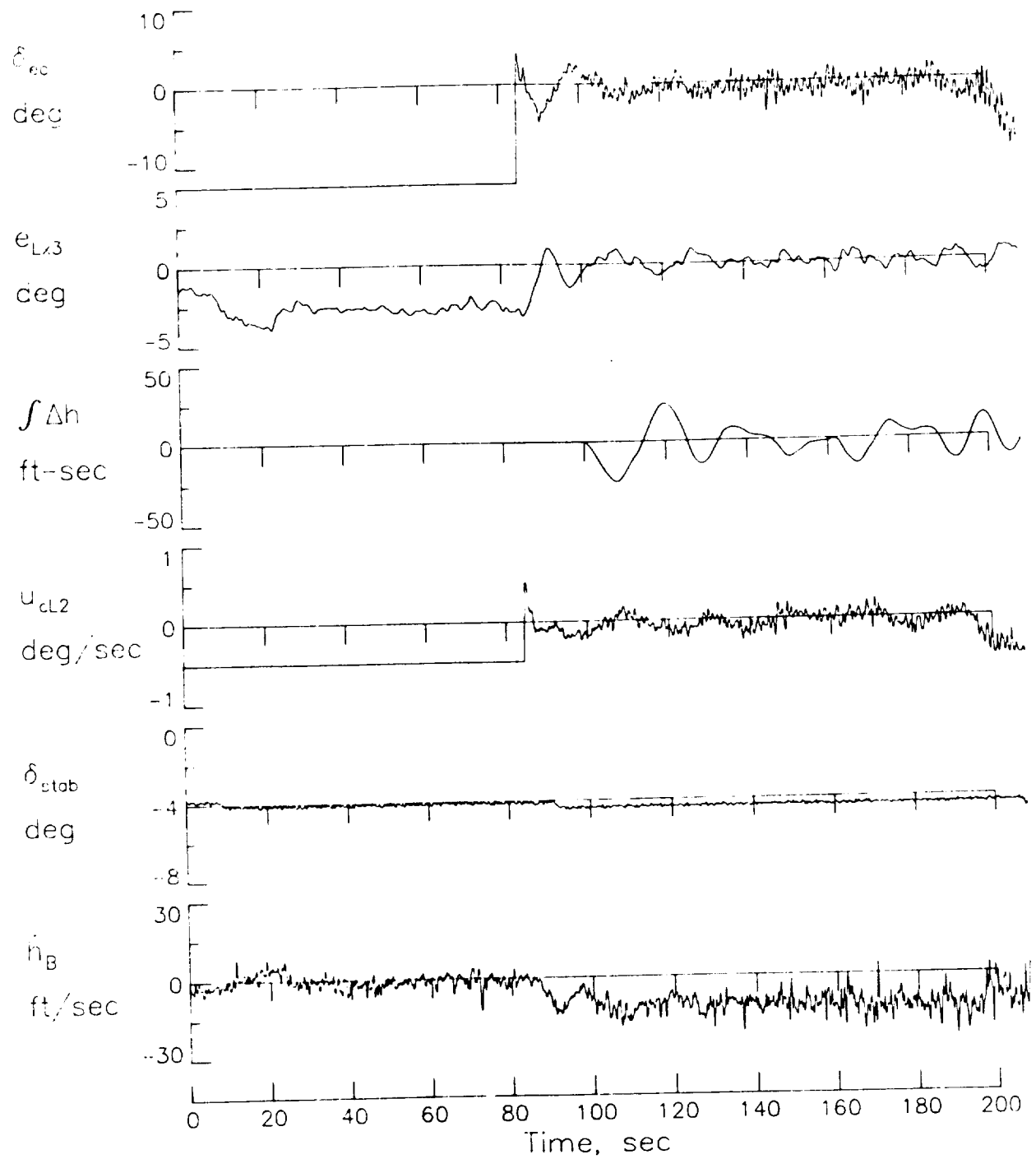


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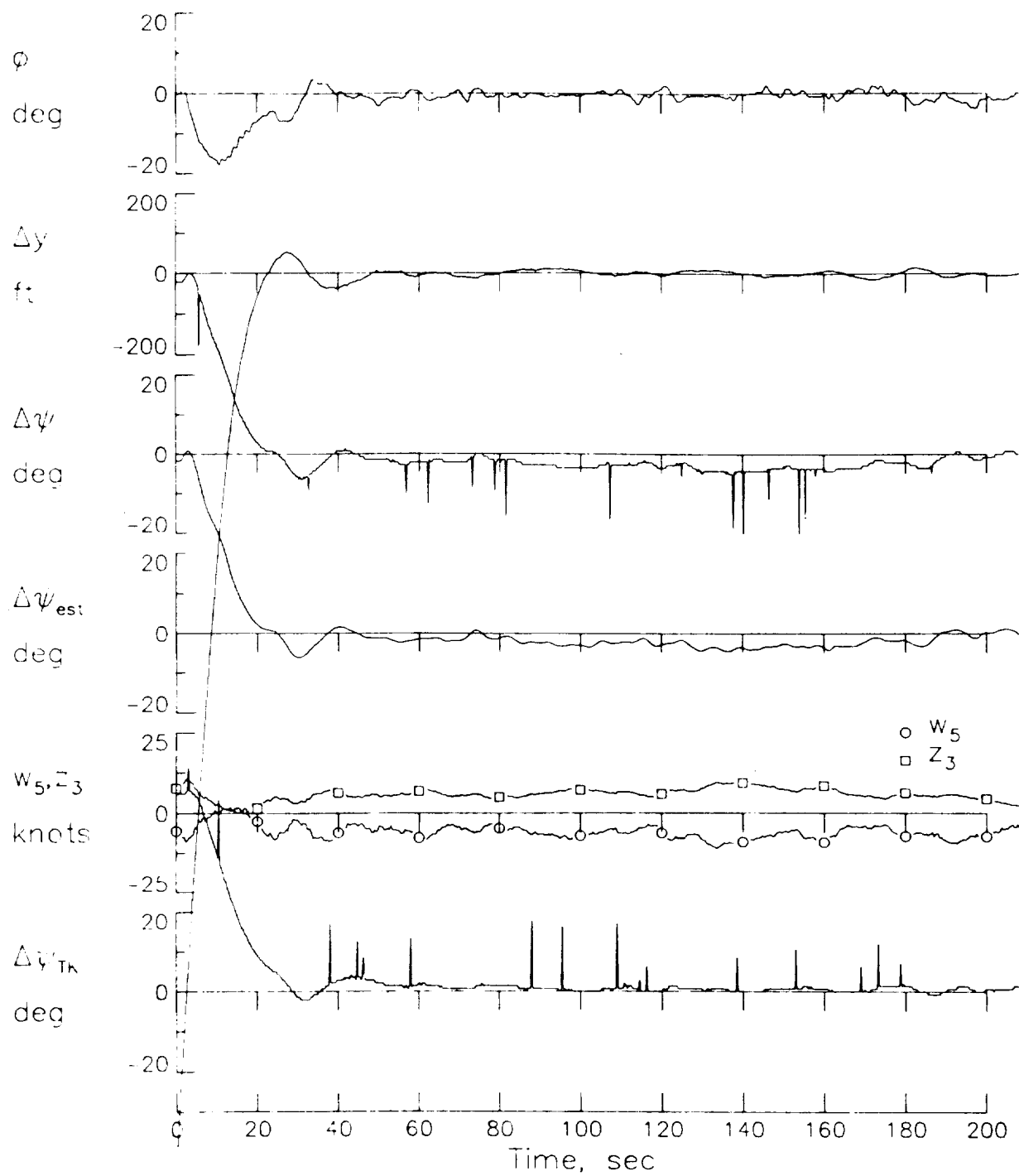


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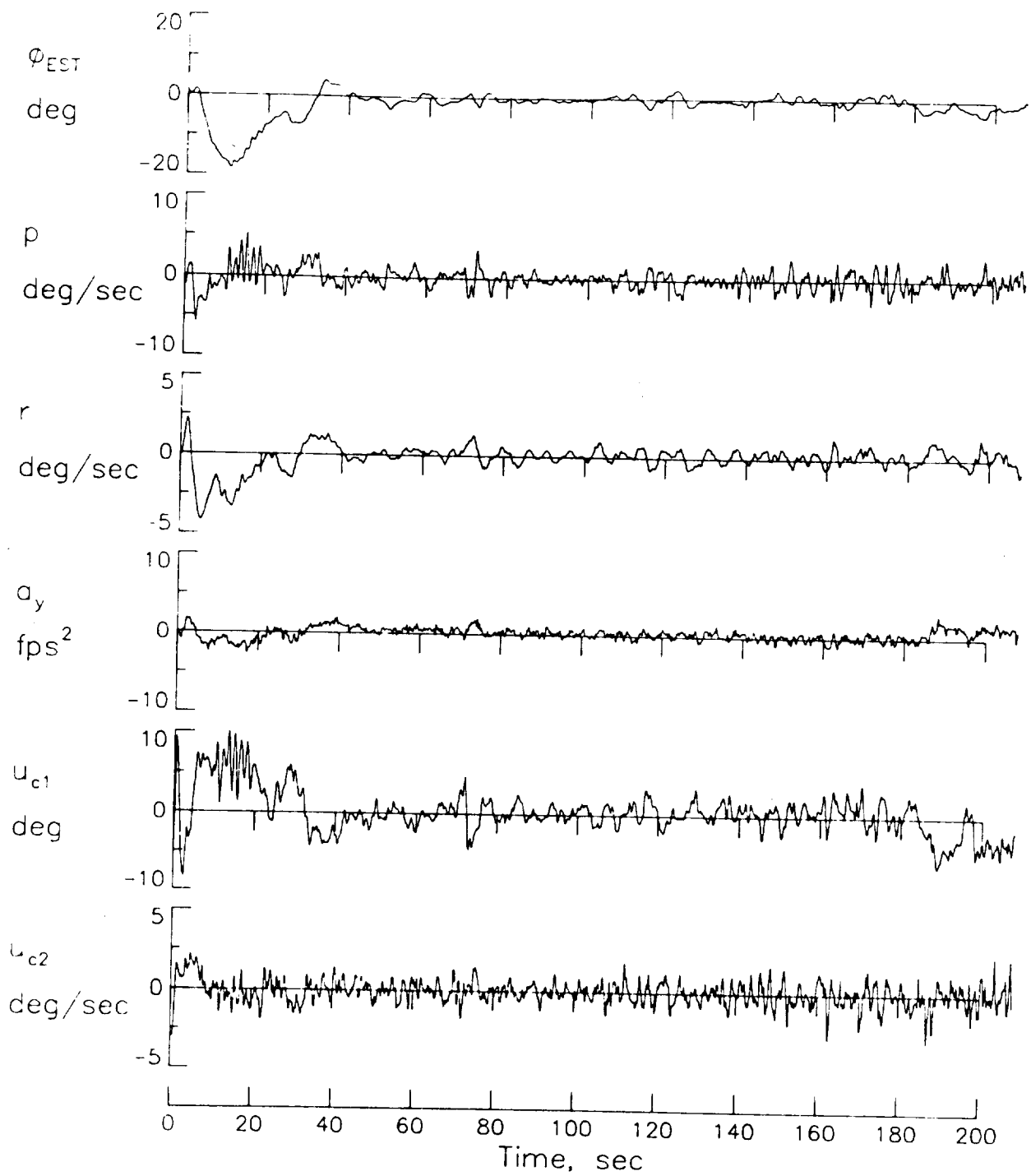


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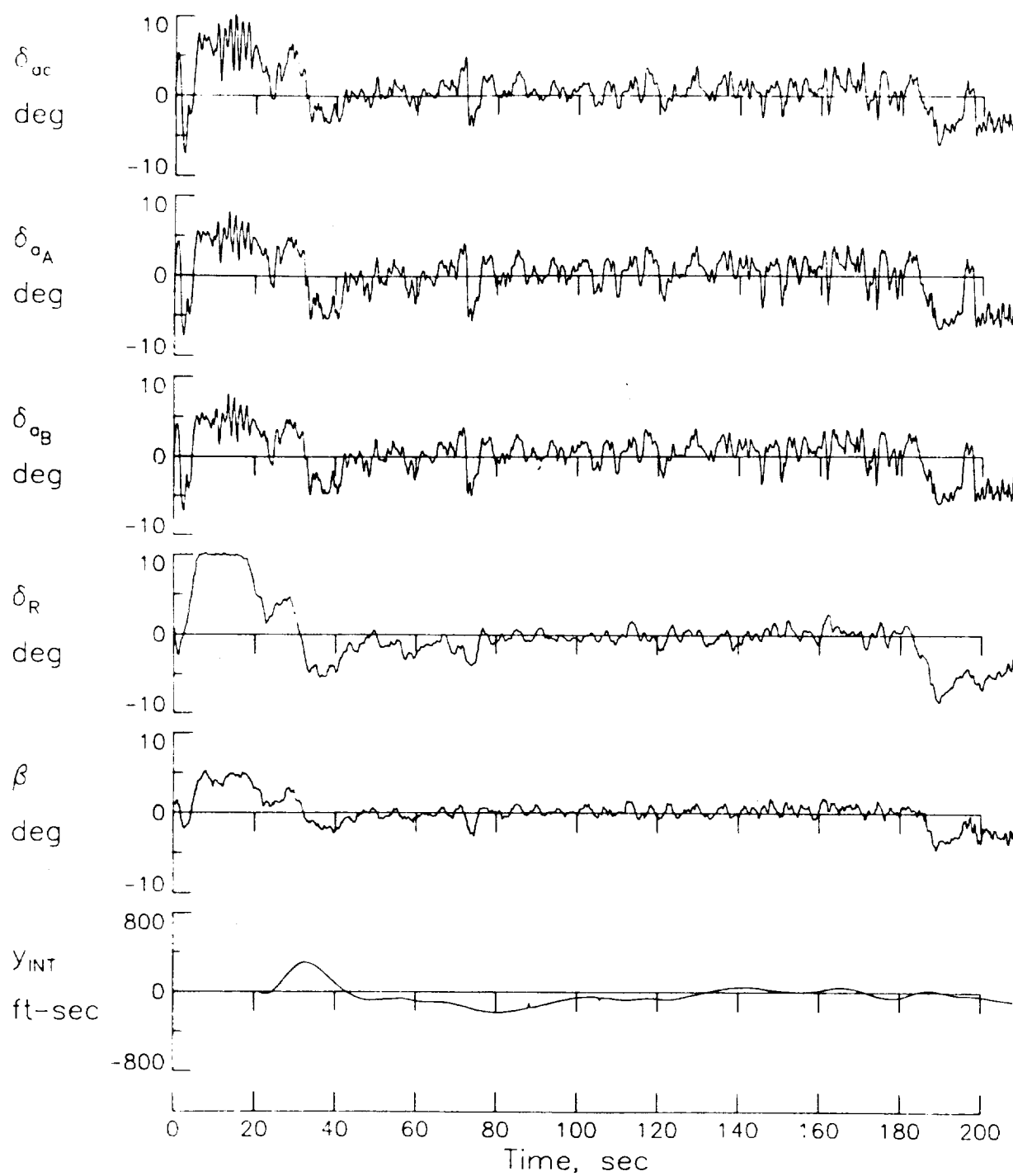


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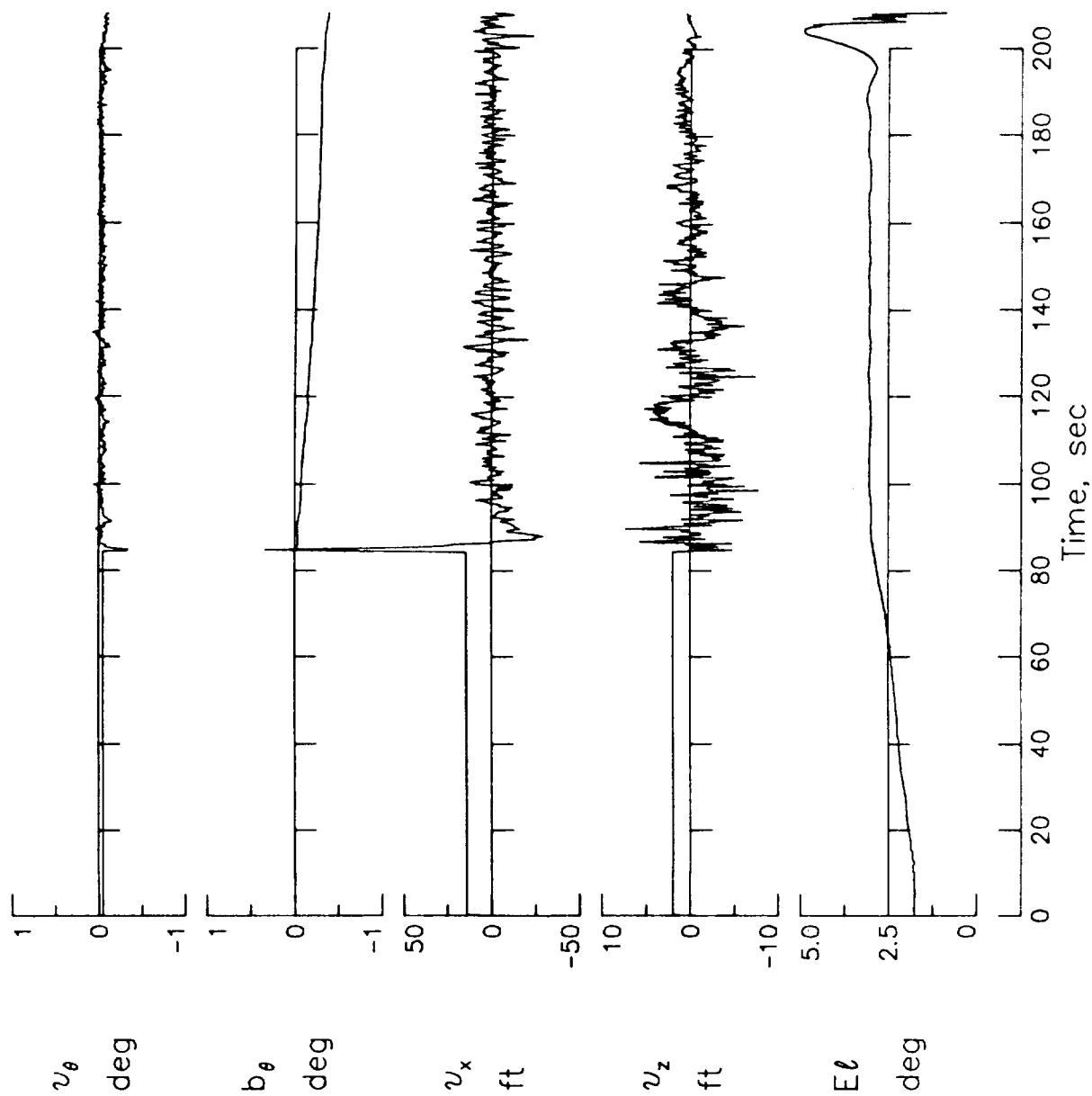


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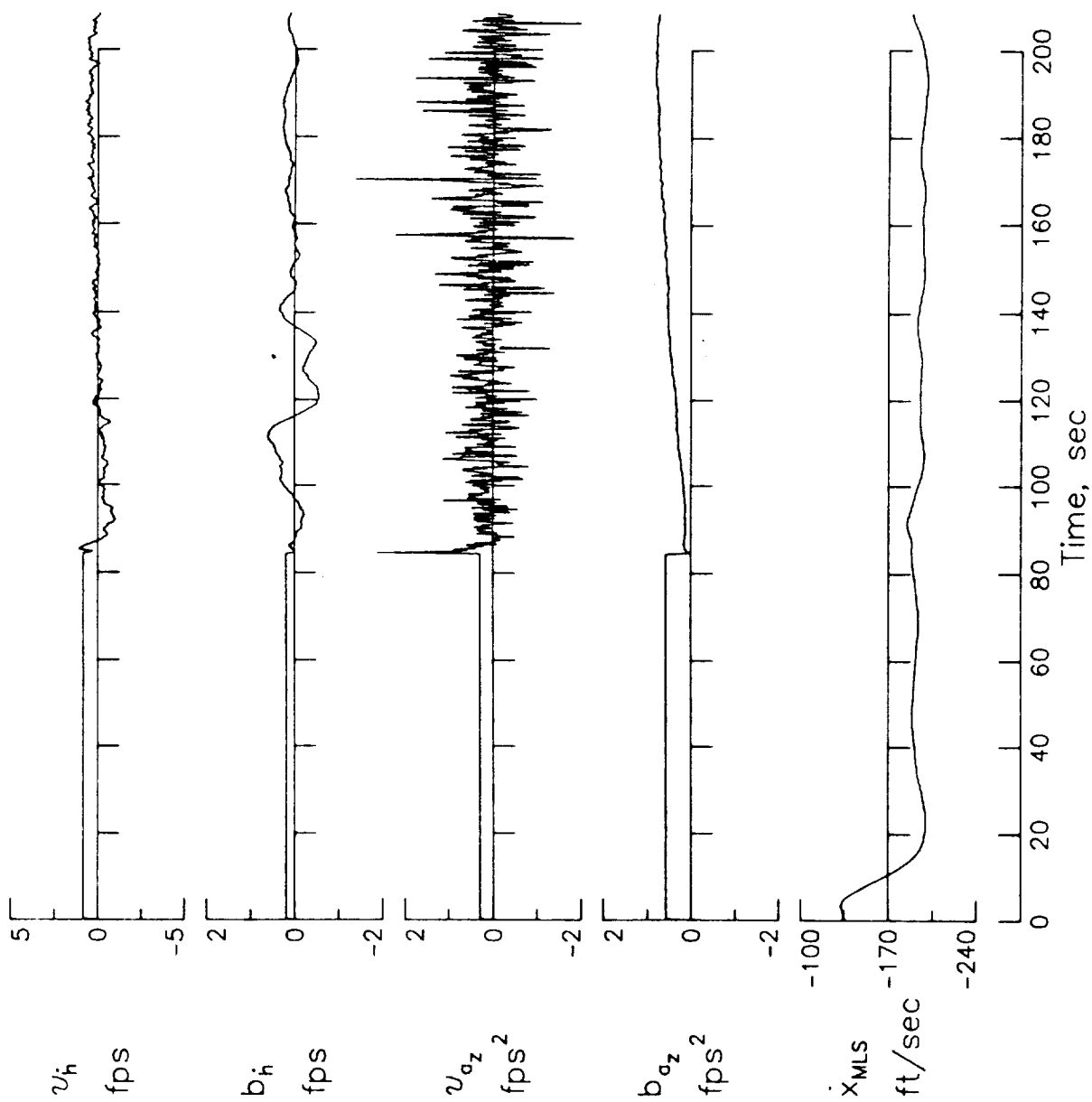


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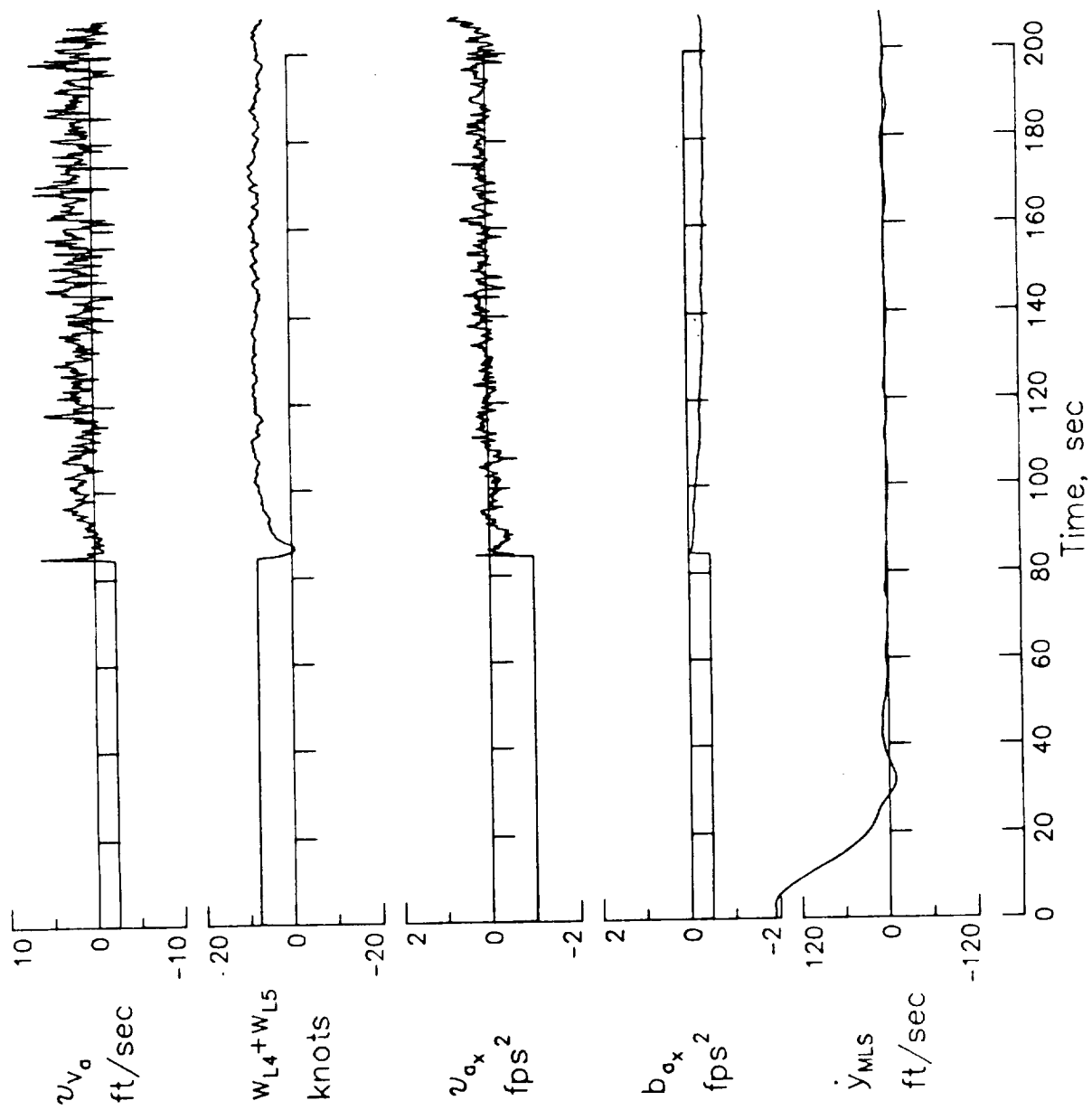


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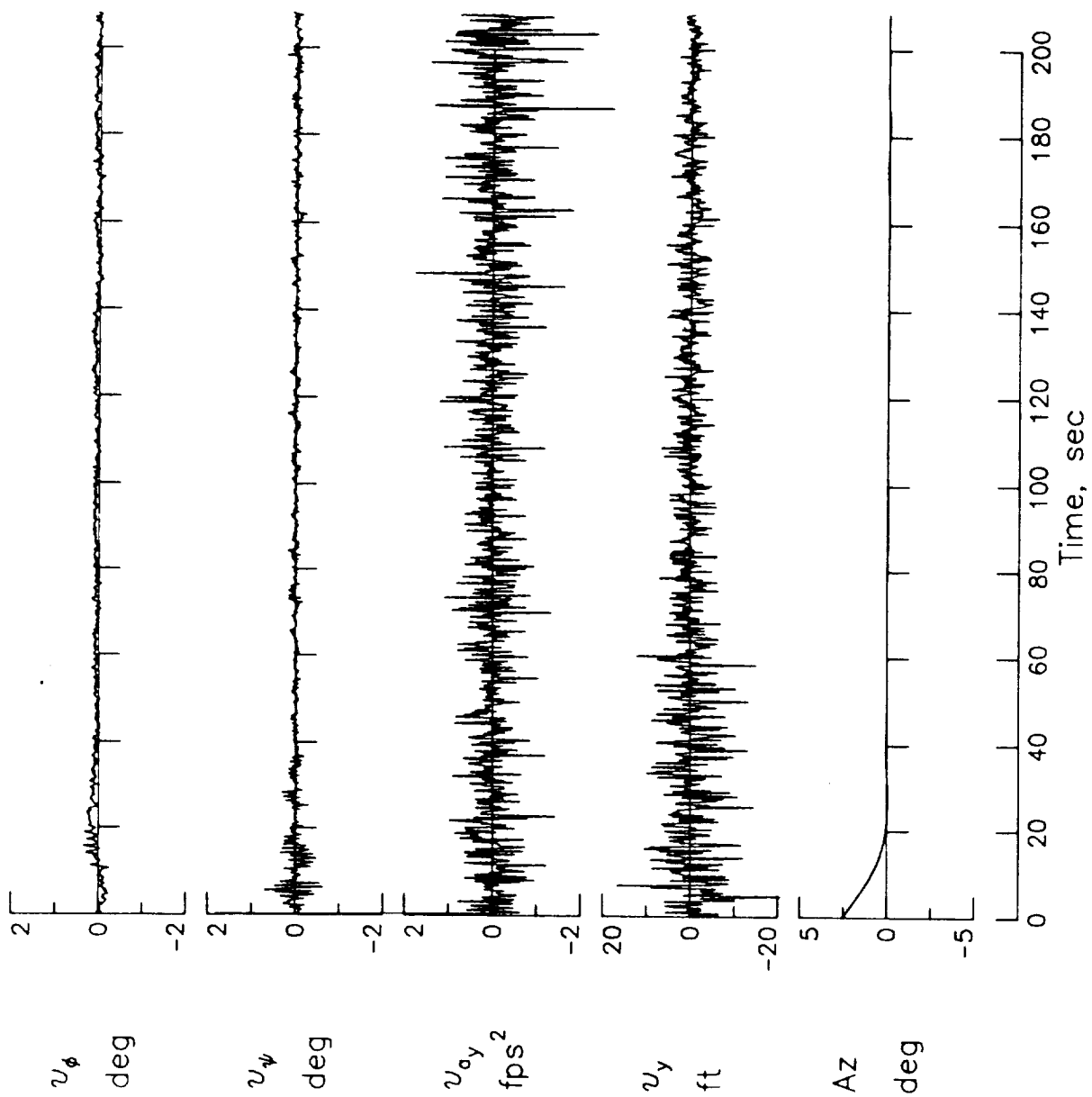


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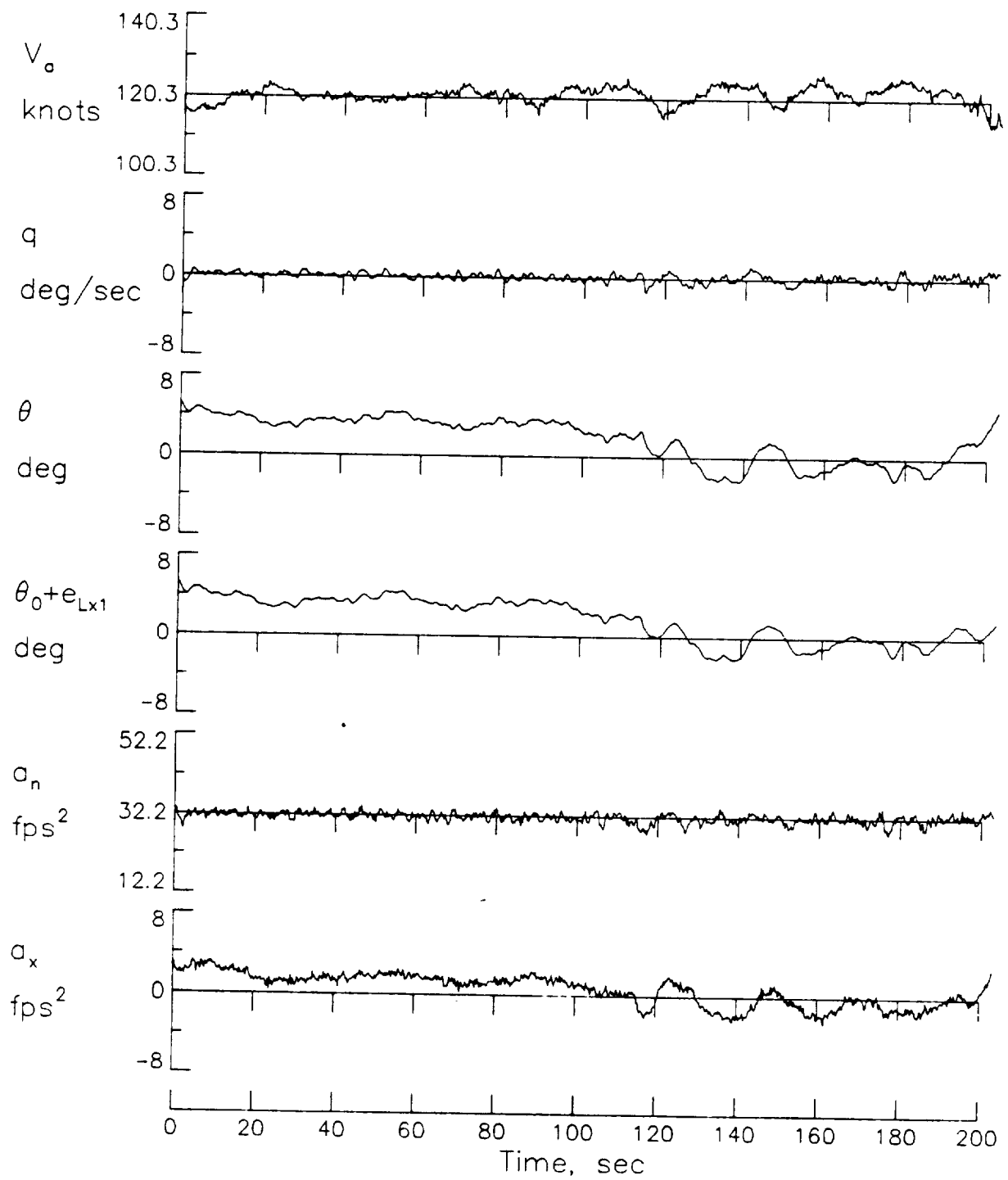


Figure 13. Flight Data for DIALS Flight Test
R355, Run 11

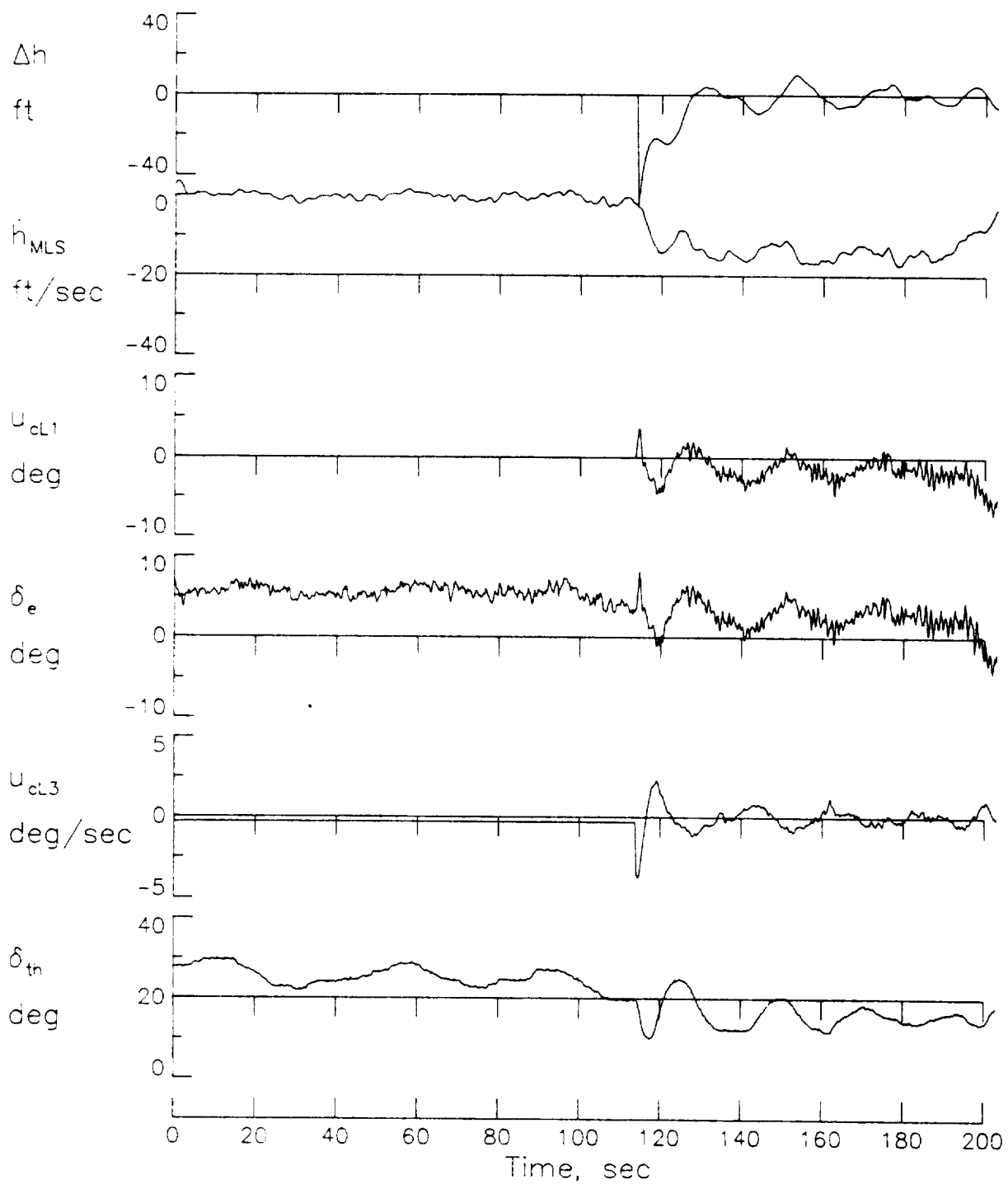


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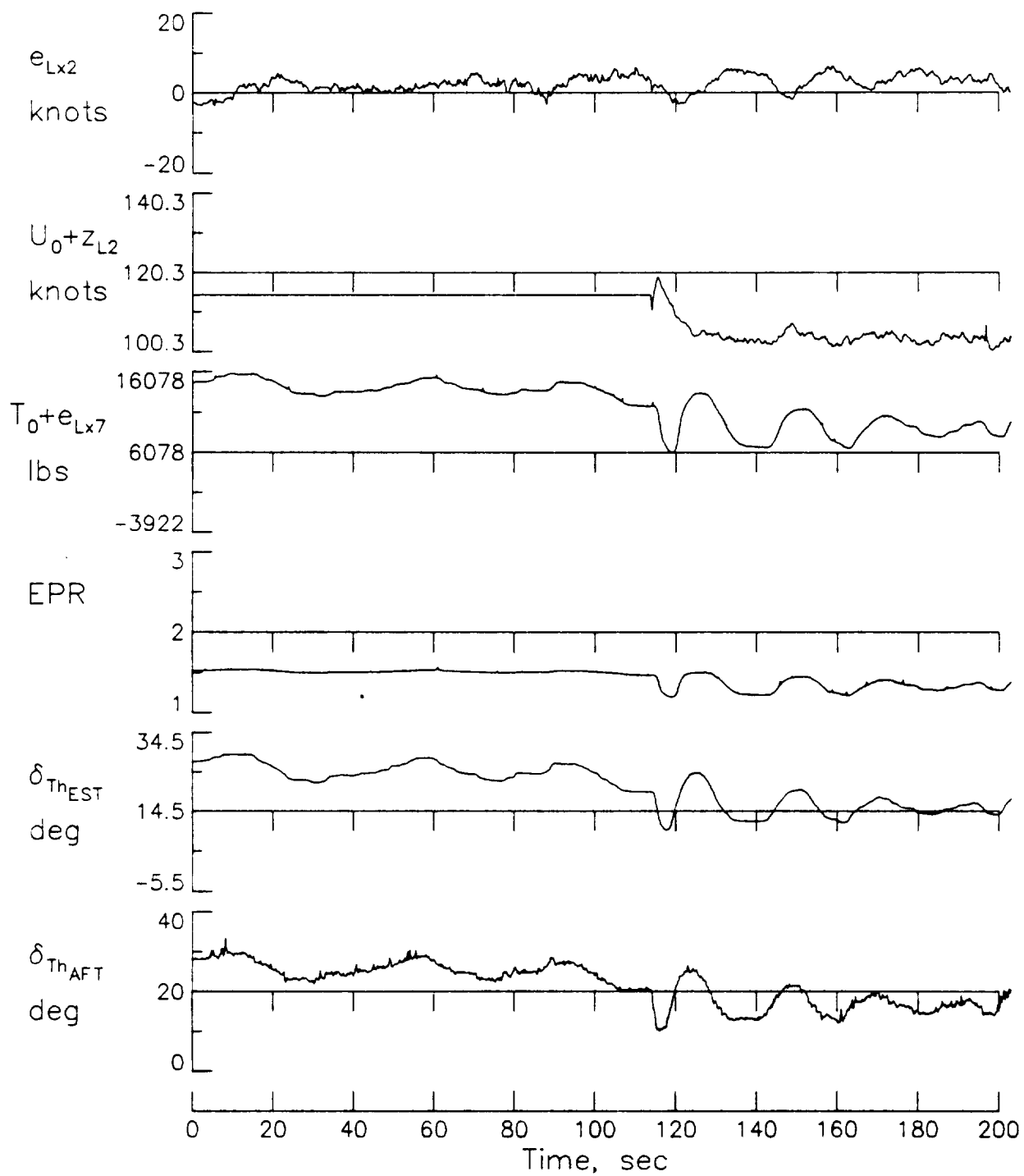


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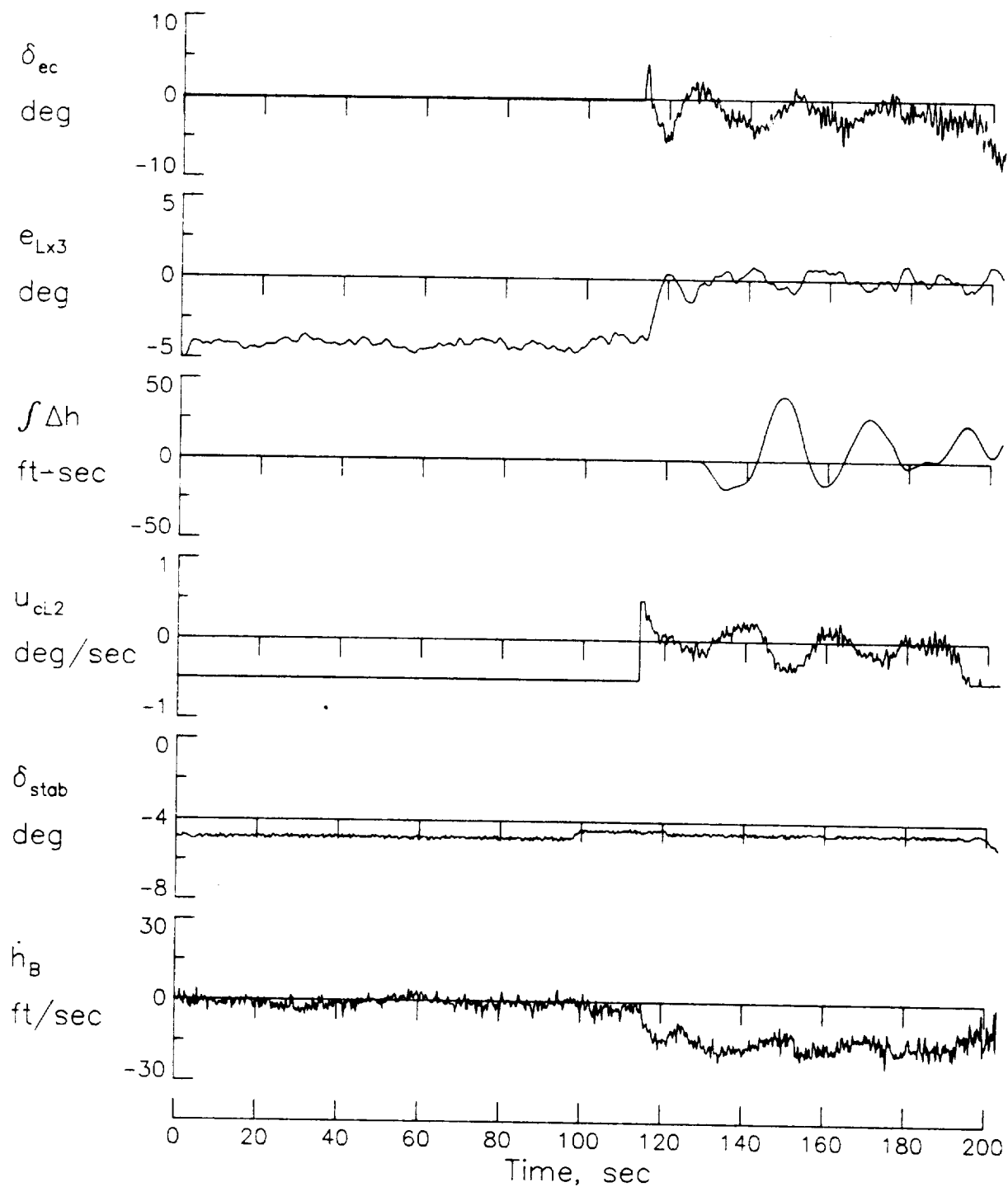


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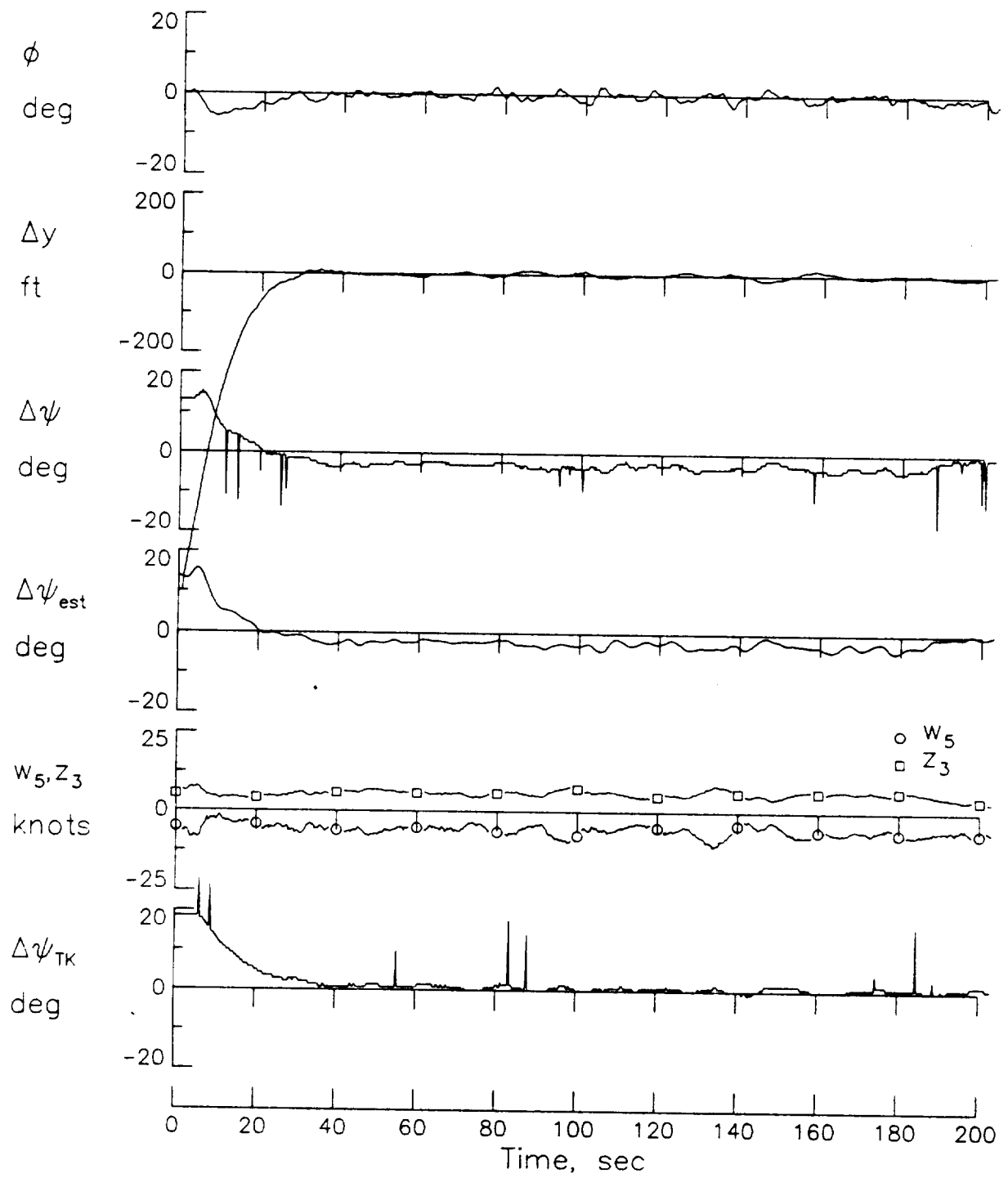


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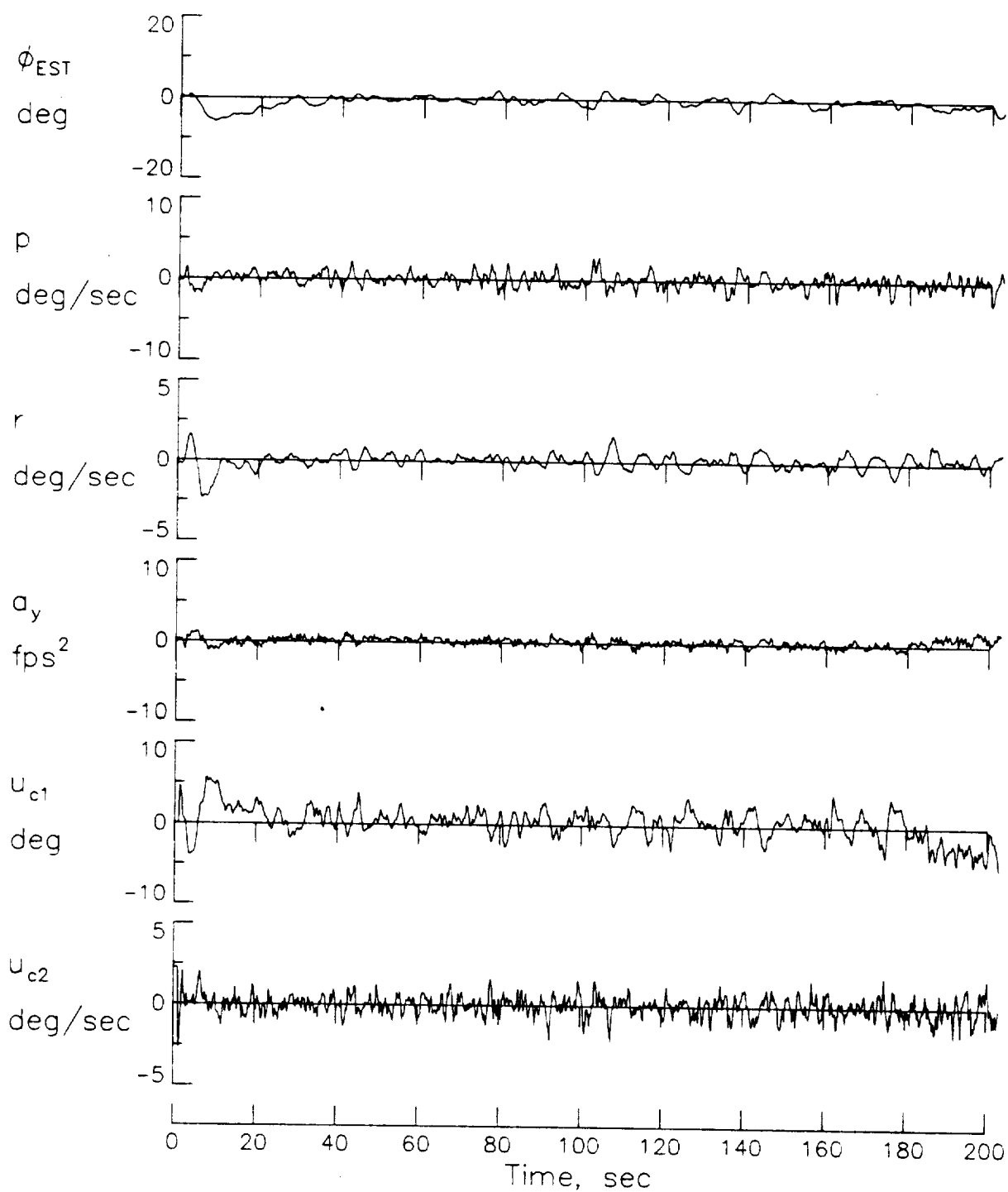


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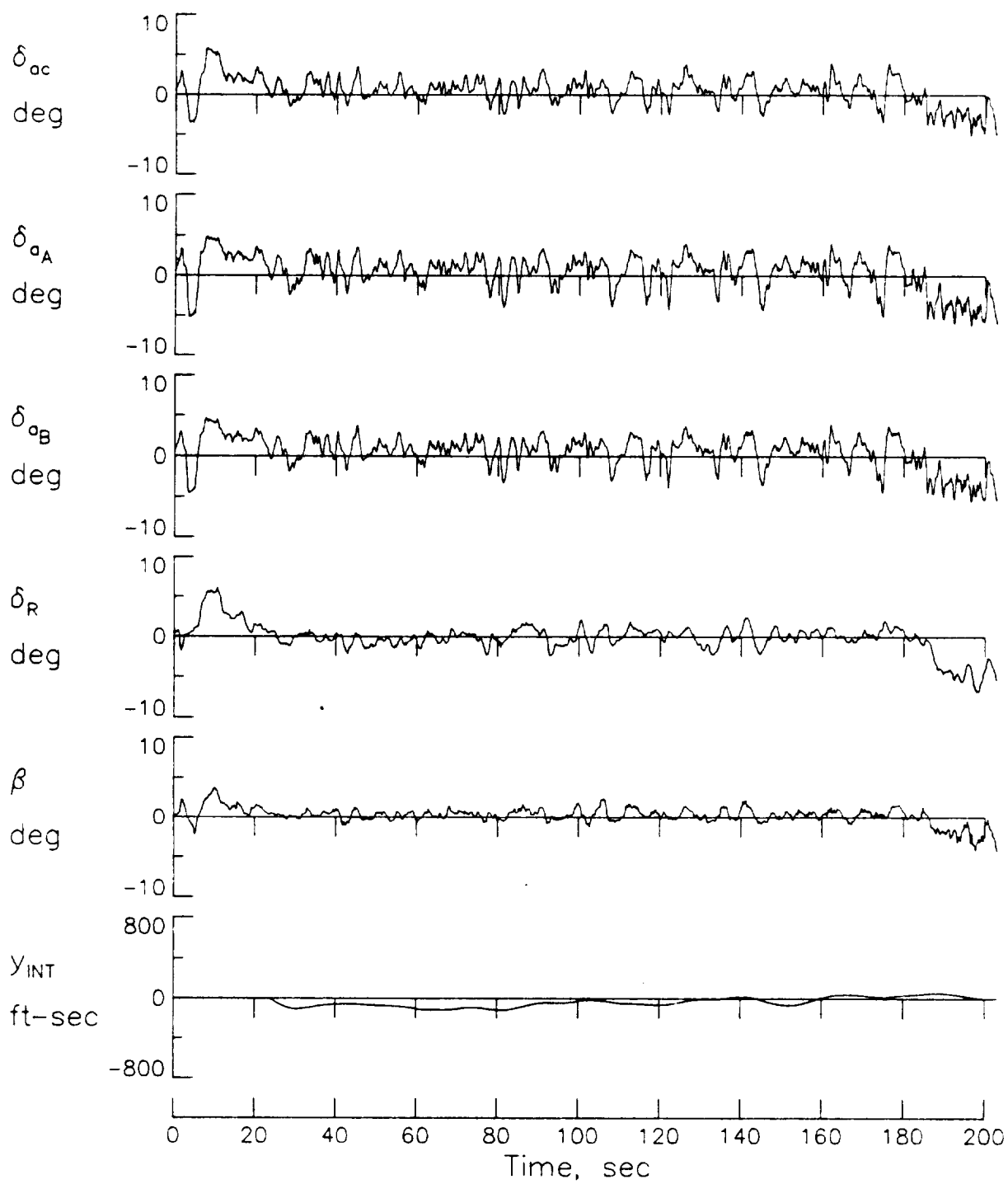


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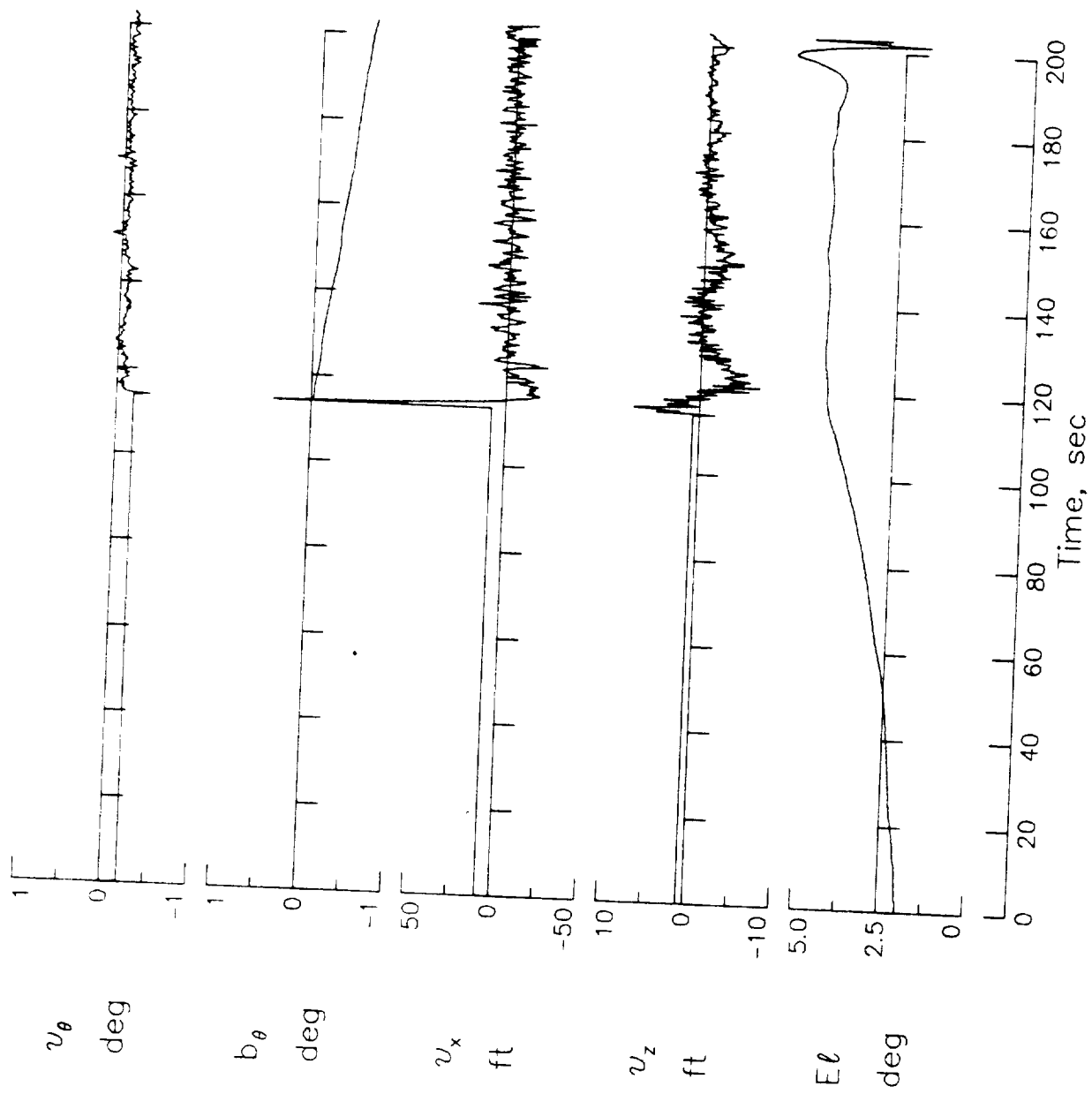


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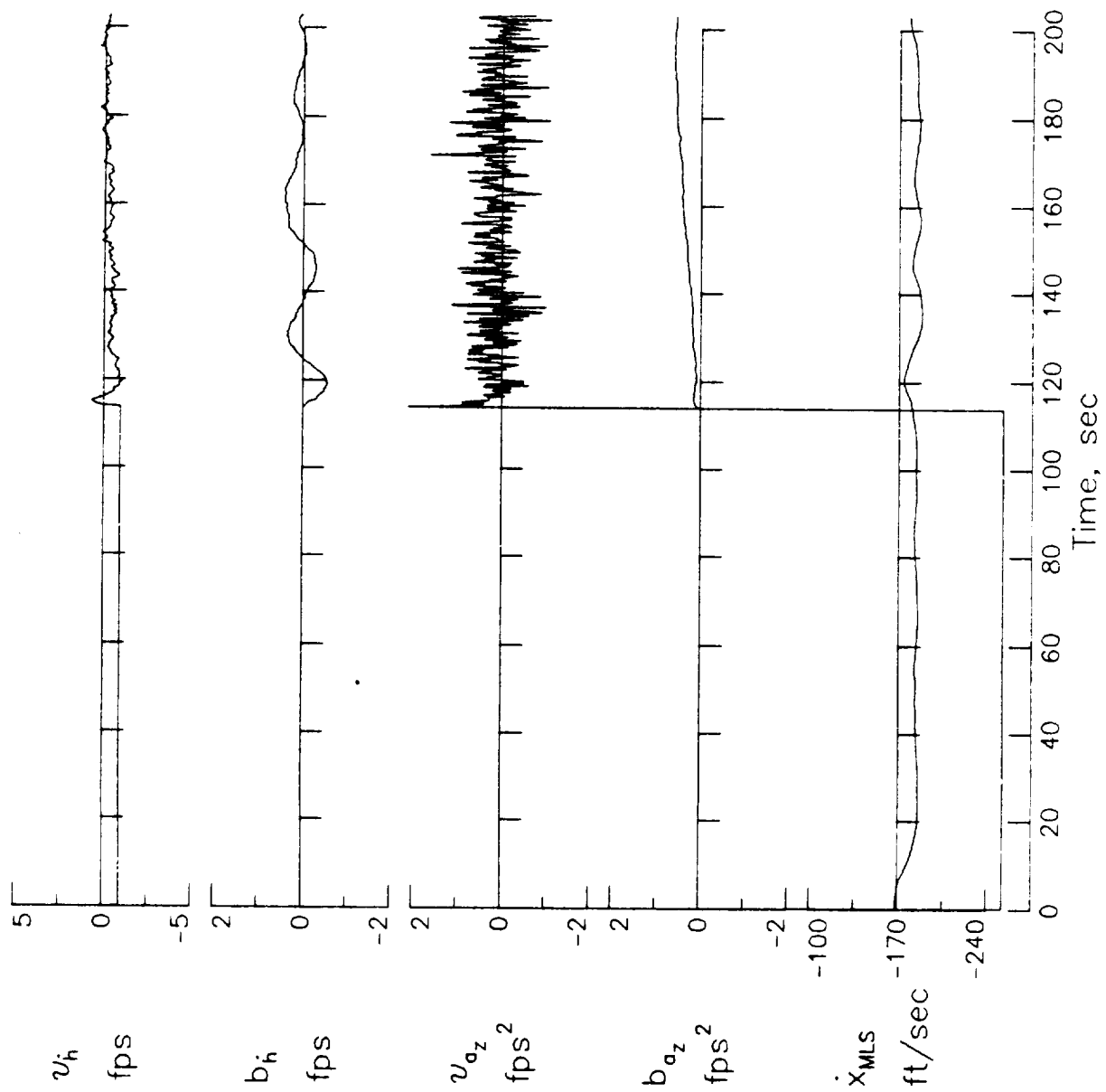


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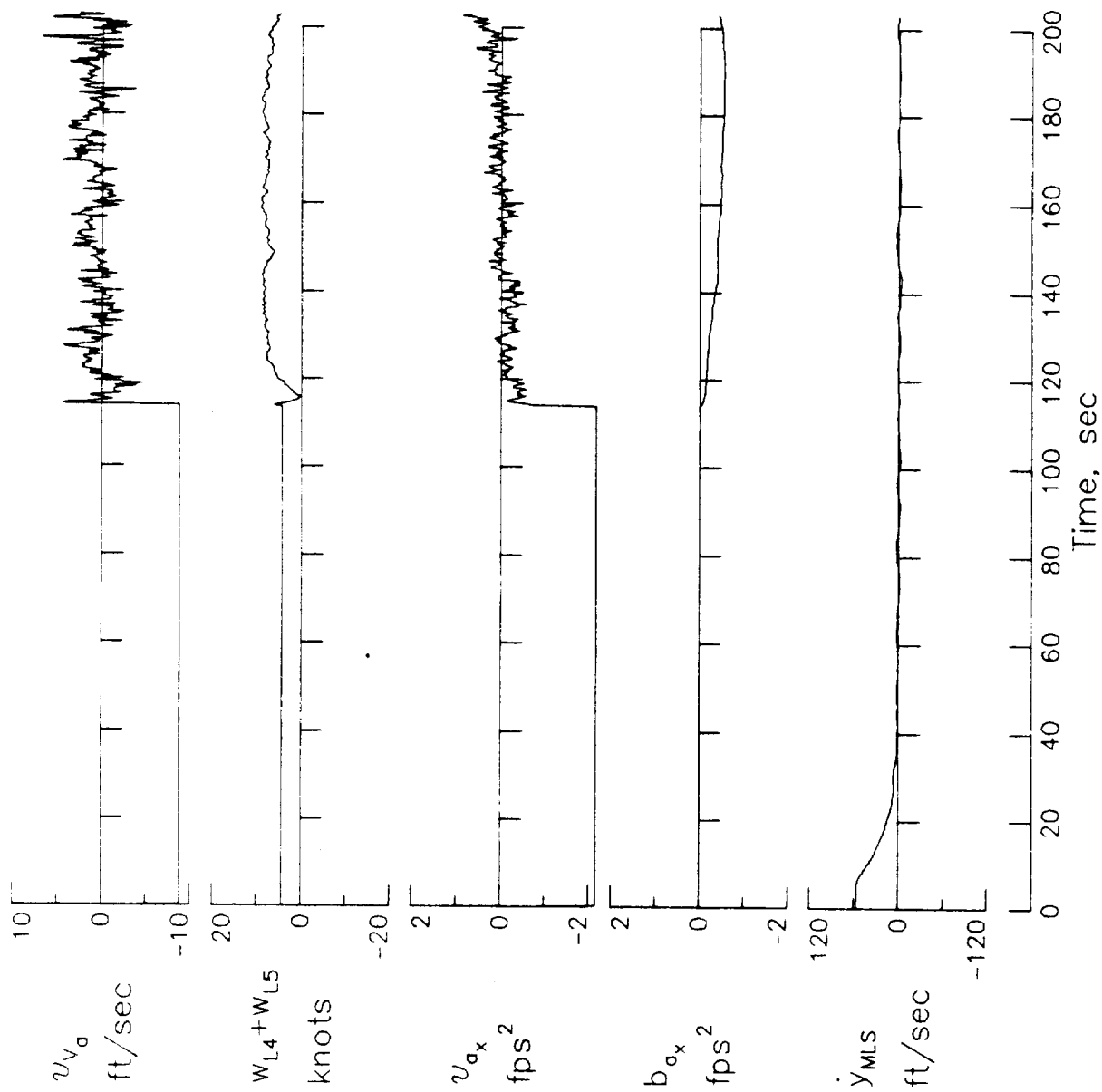


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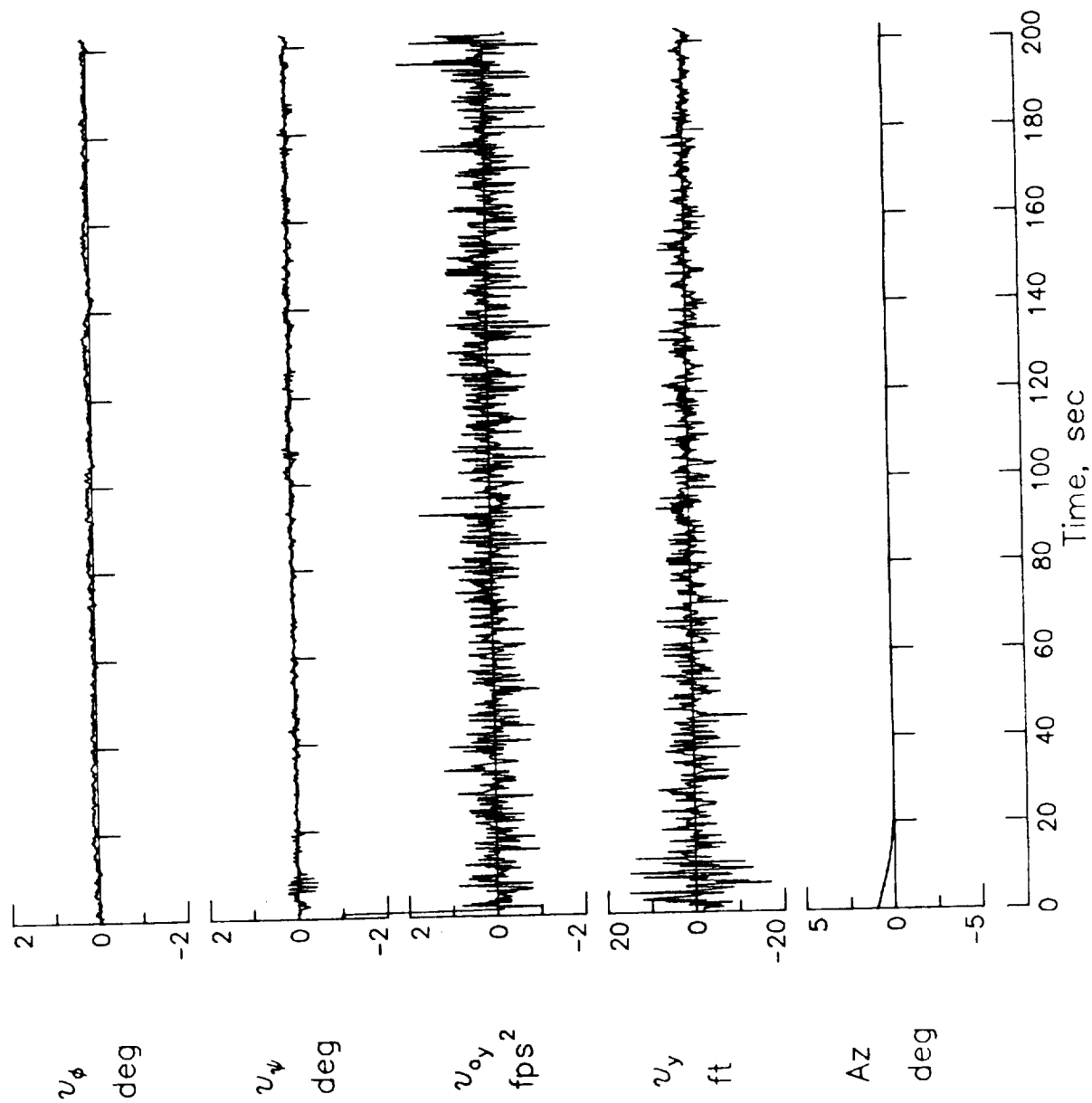


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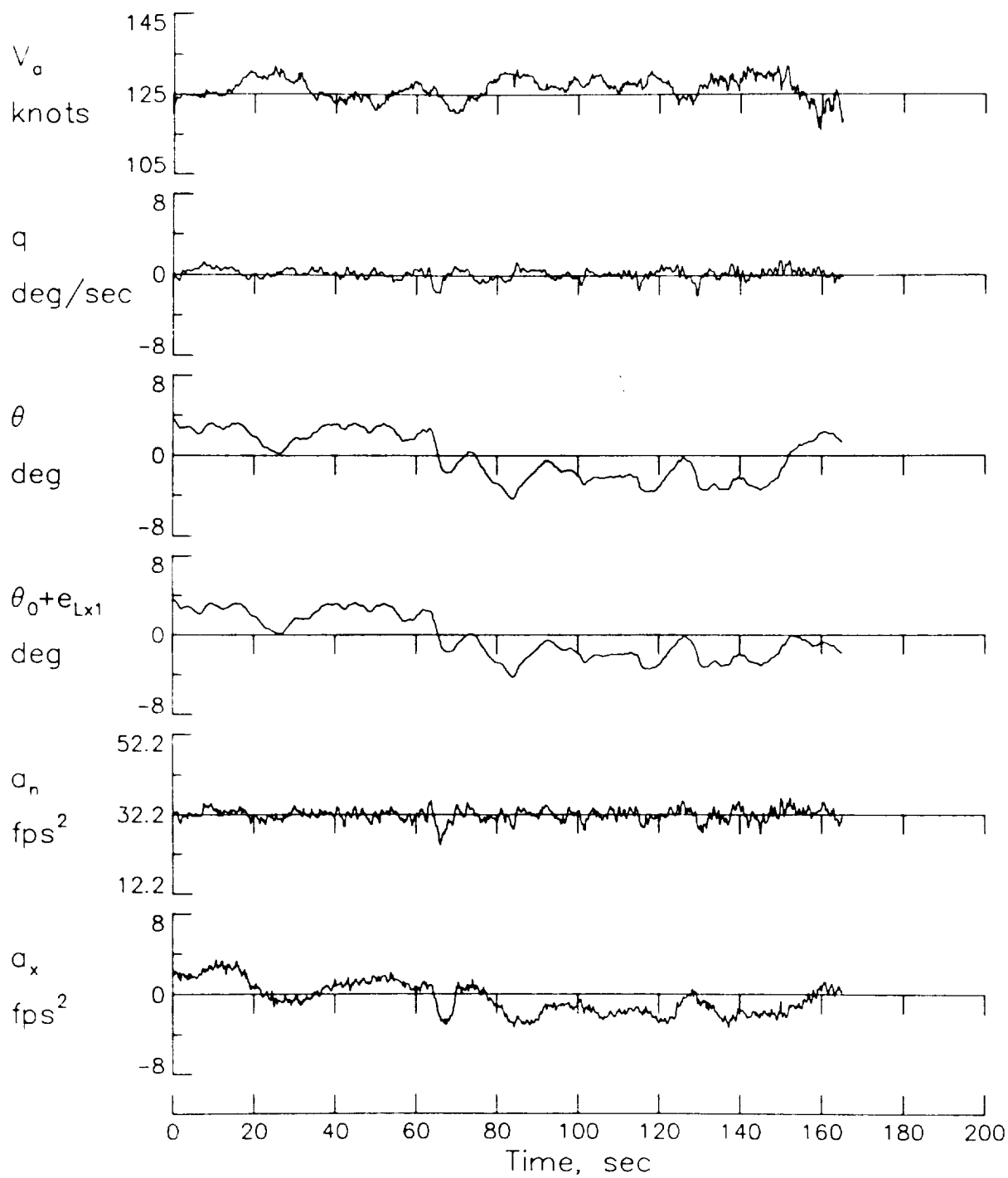


Figure 14. Flight Data for DIALS Flight Test R355, Run 13

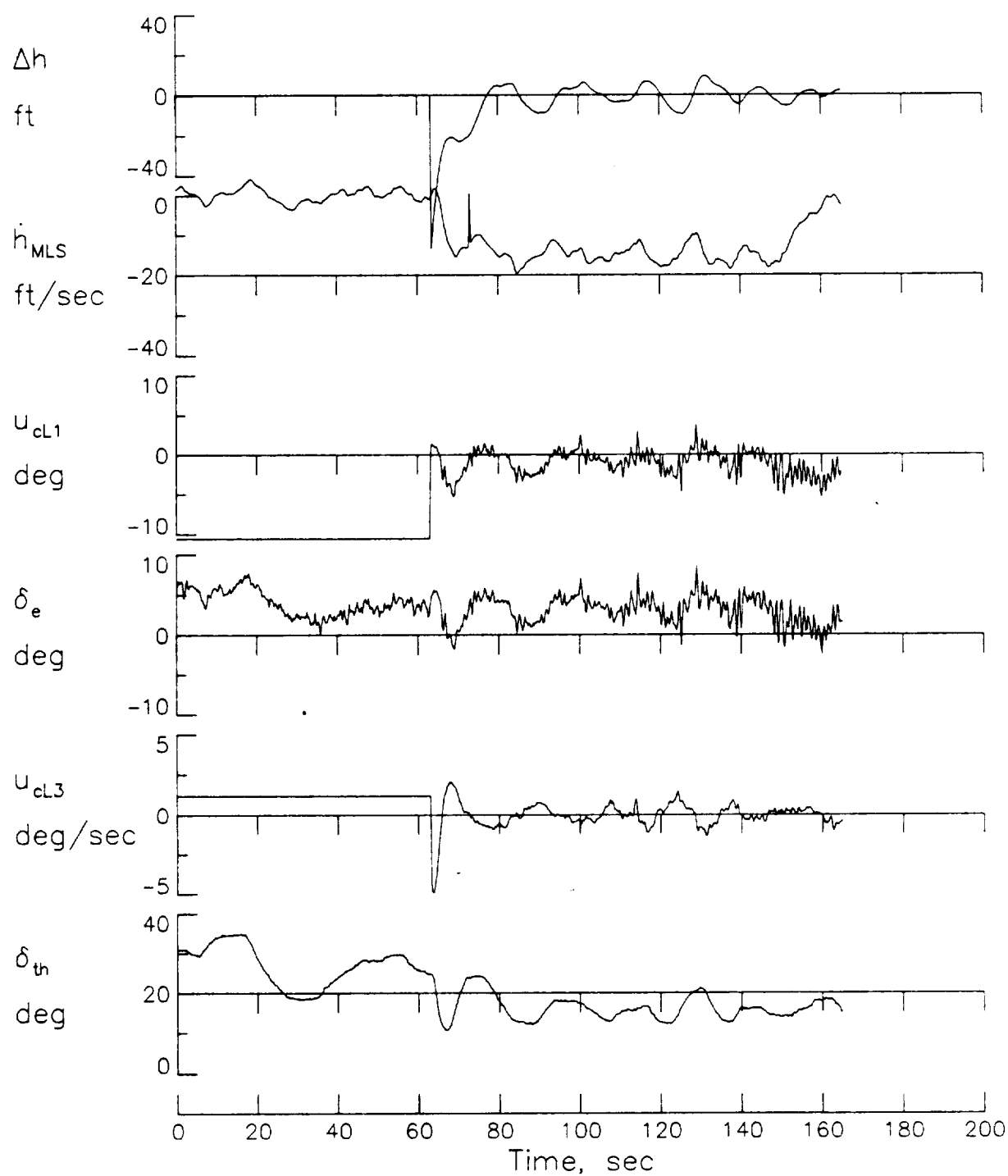


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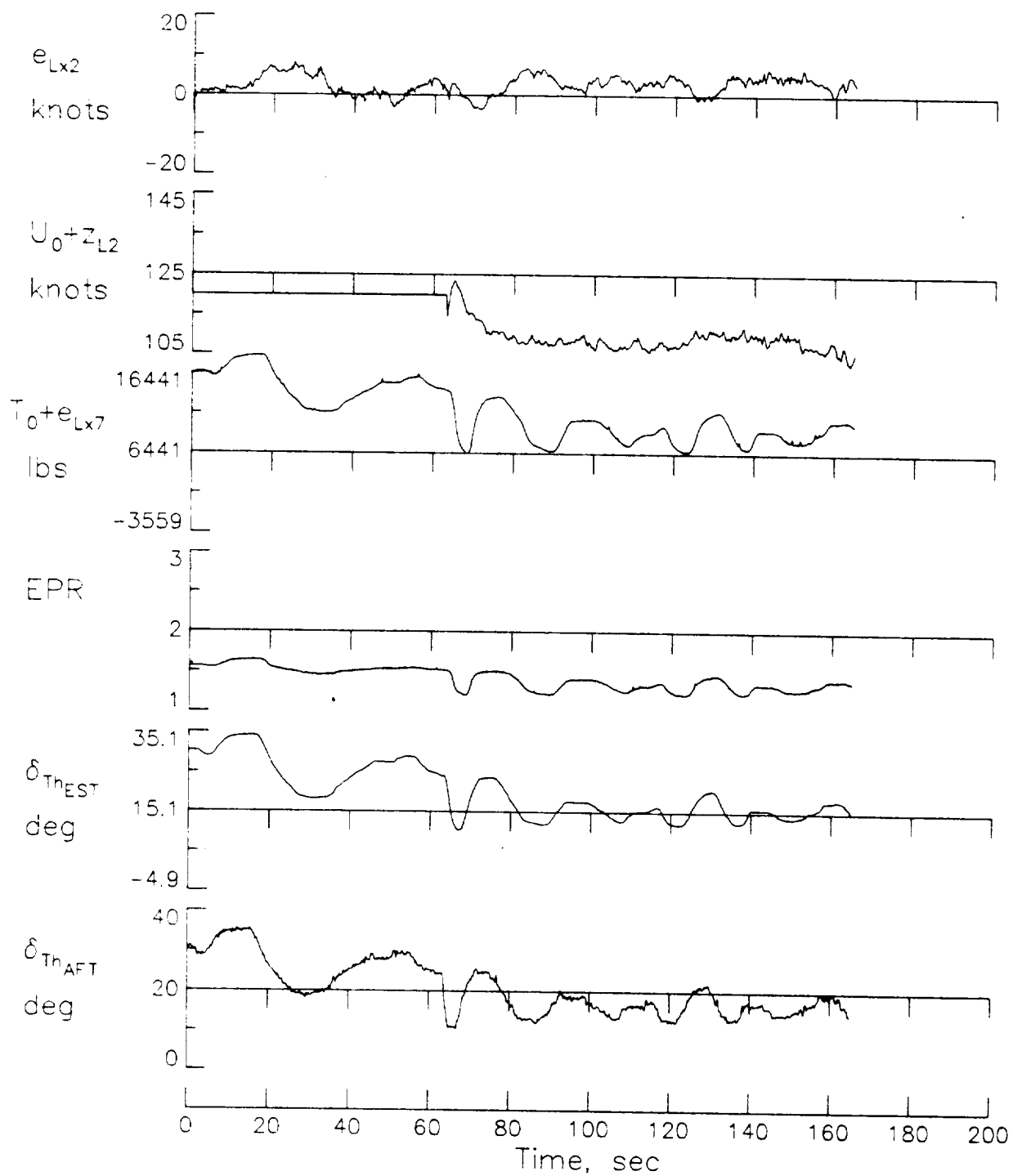


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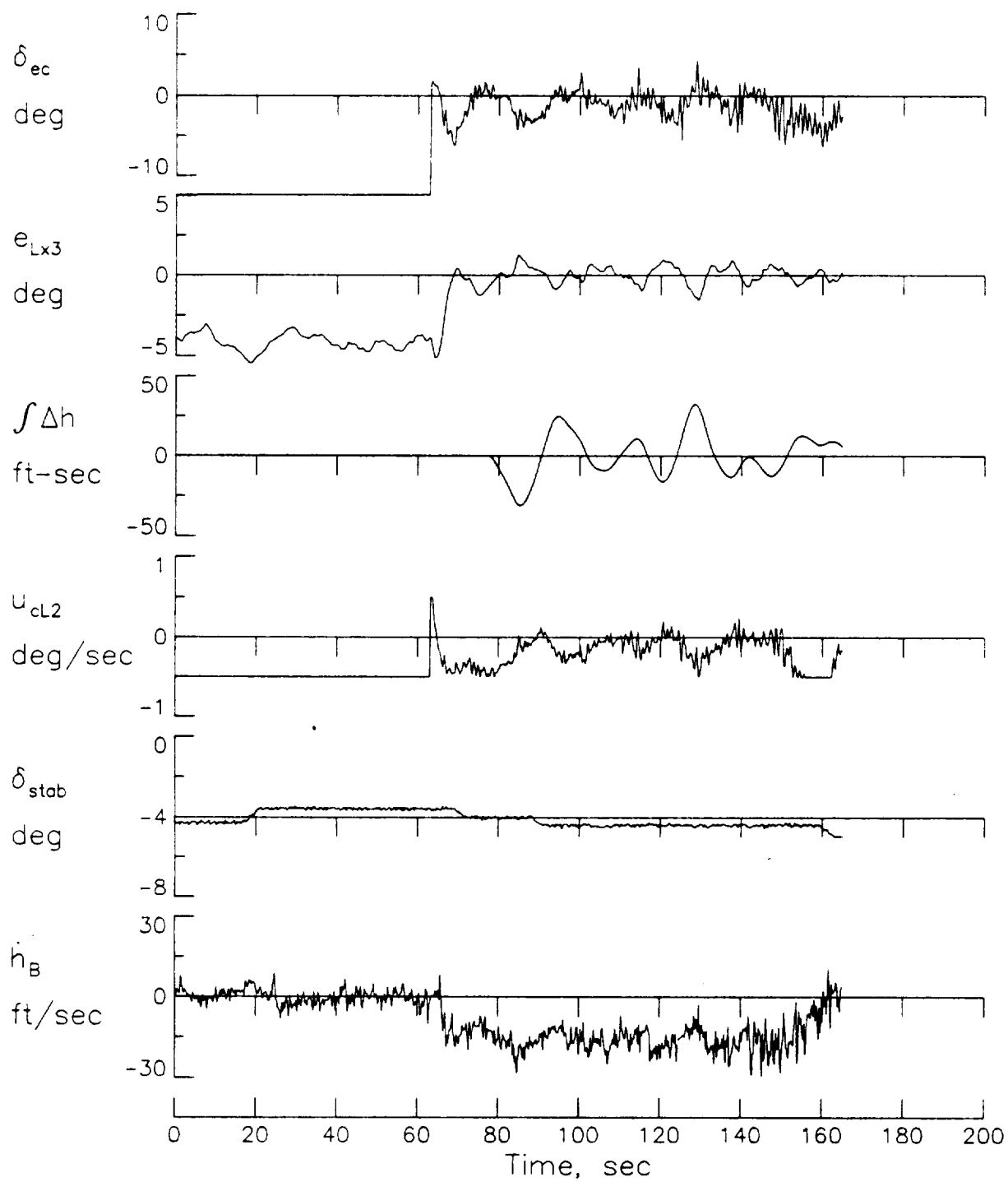


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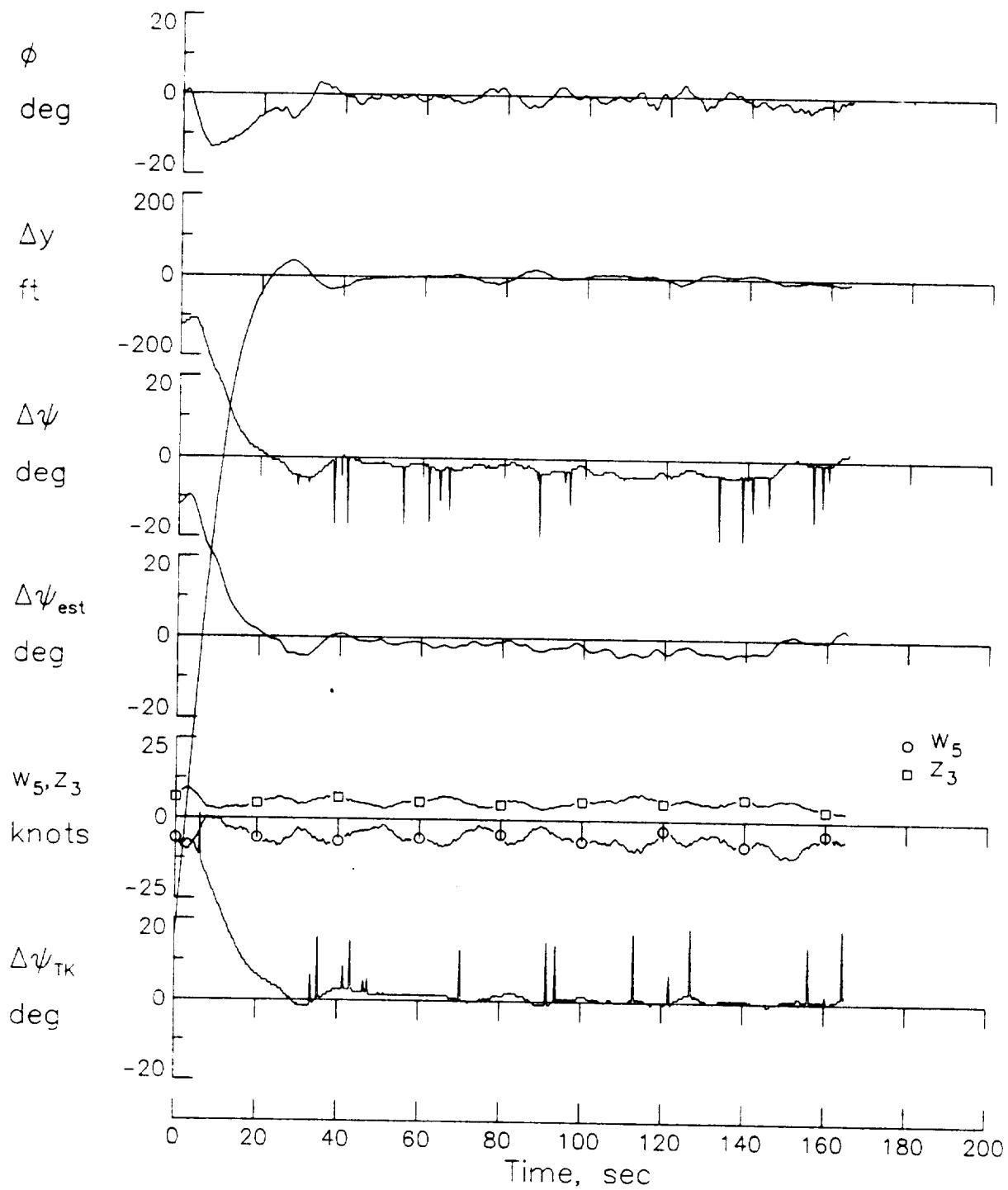


Figure 14. Continued

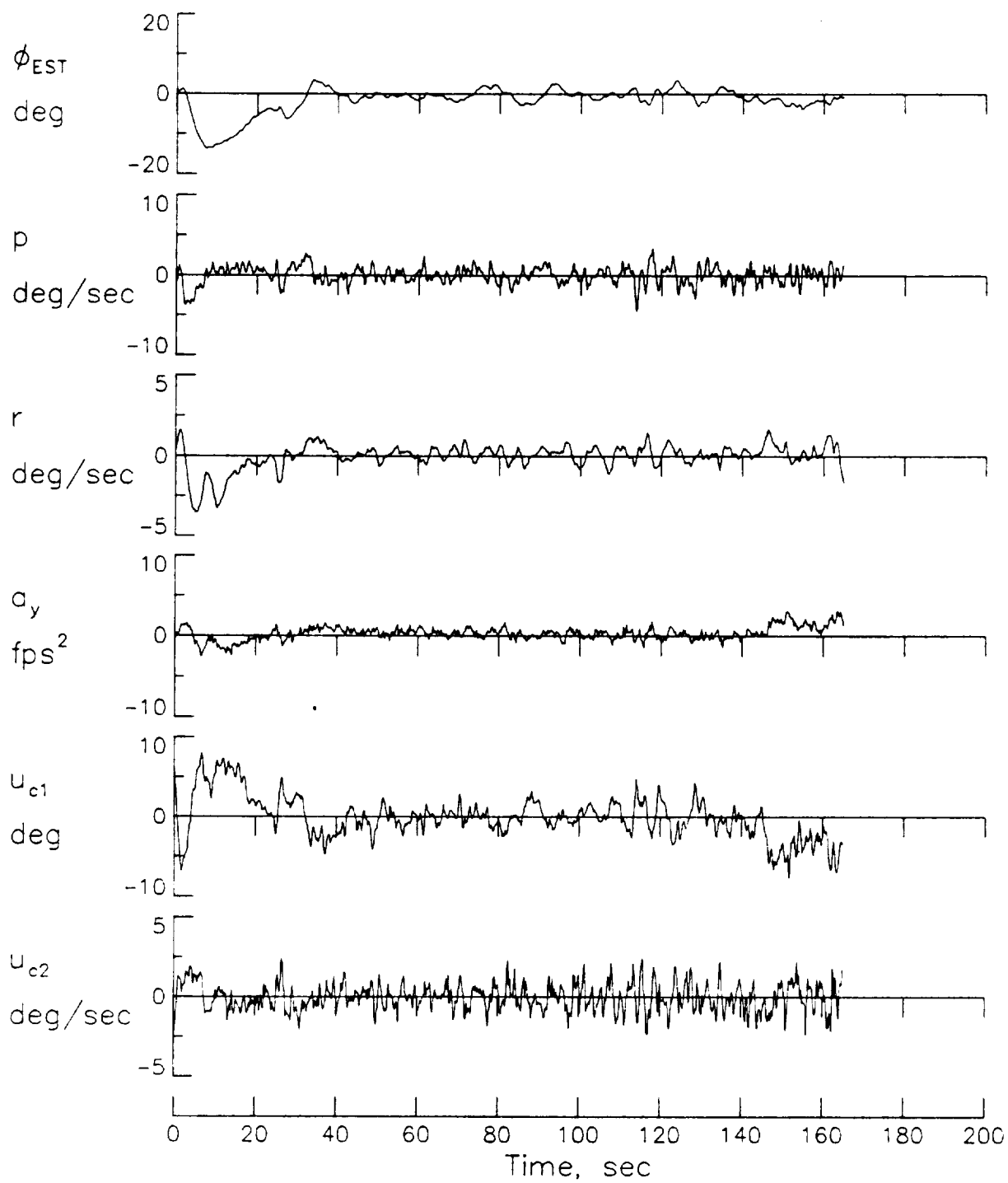


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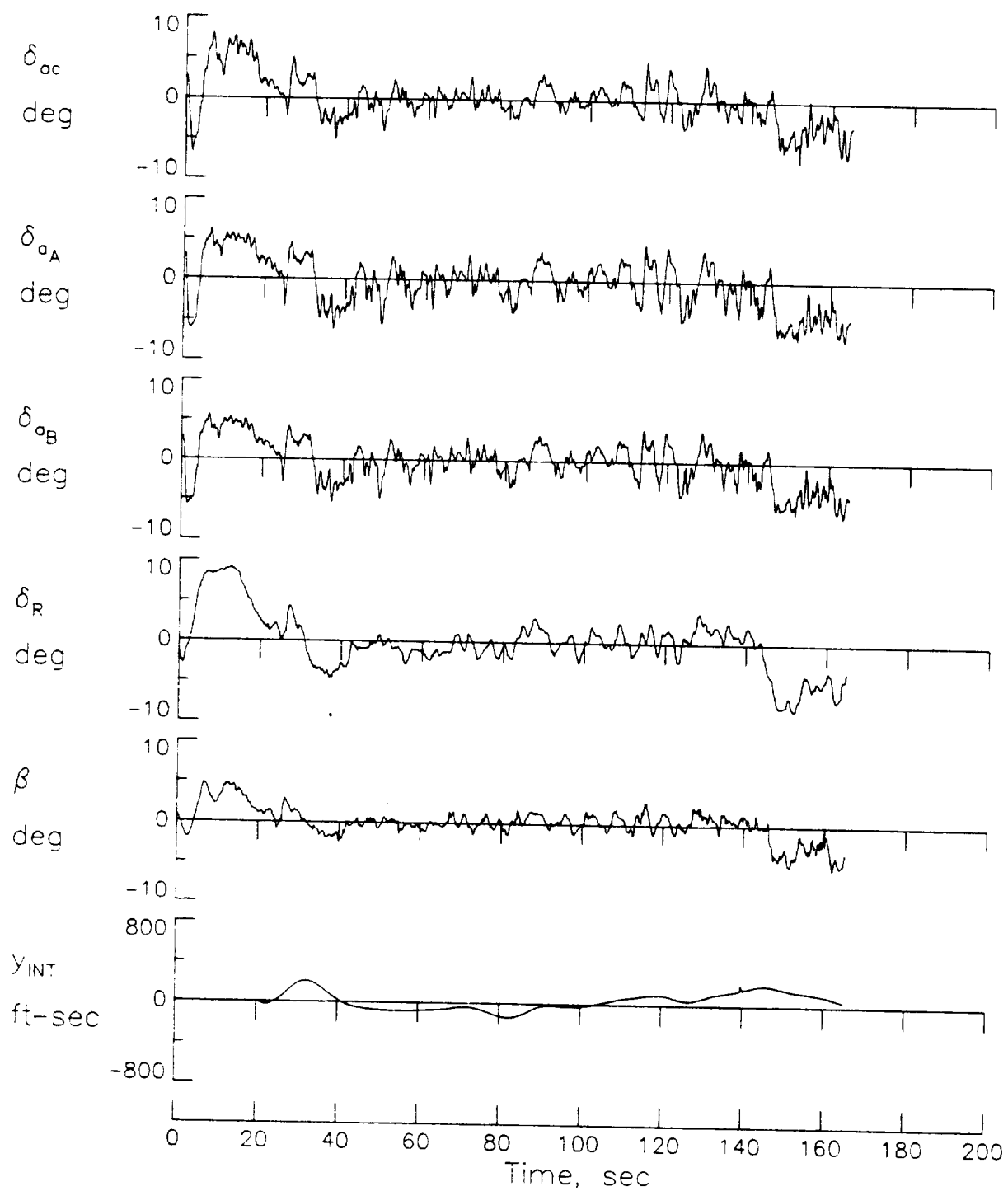


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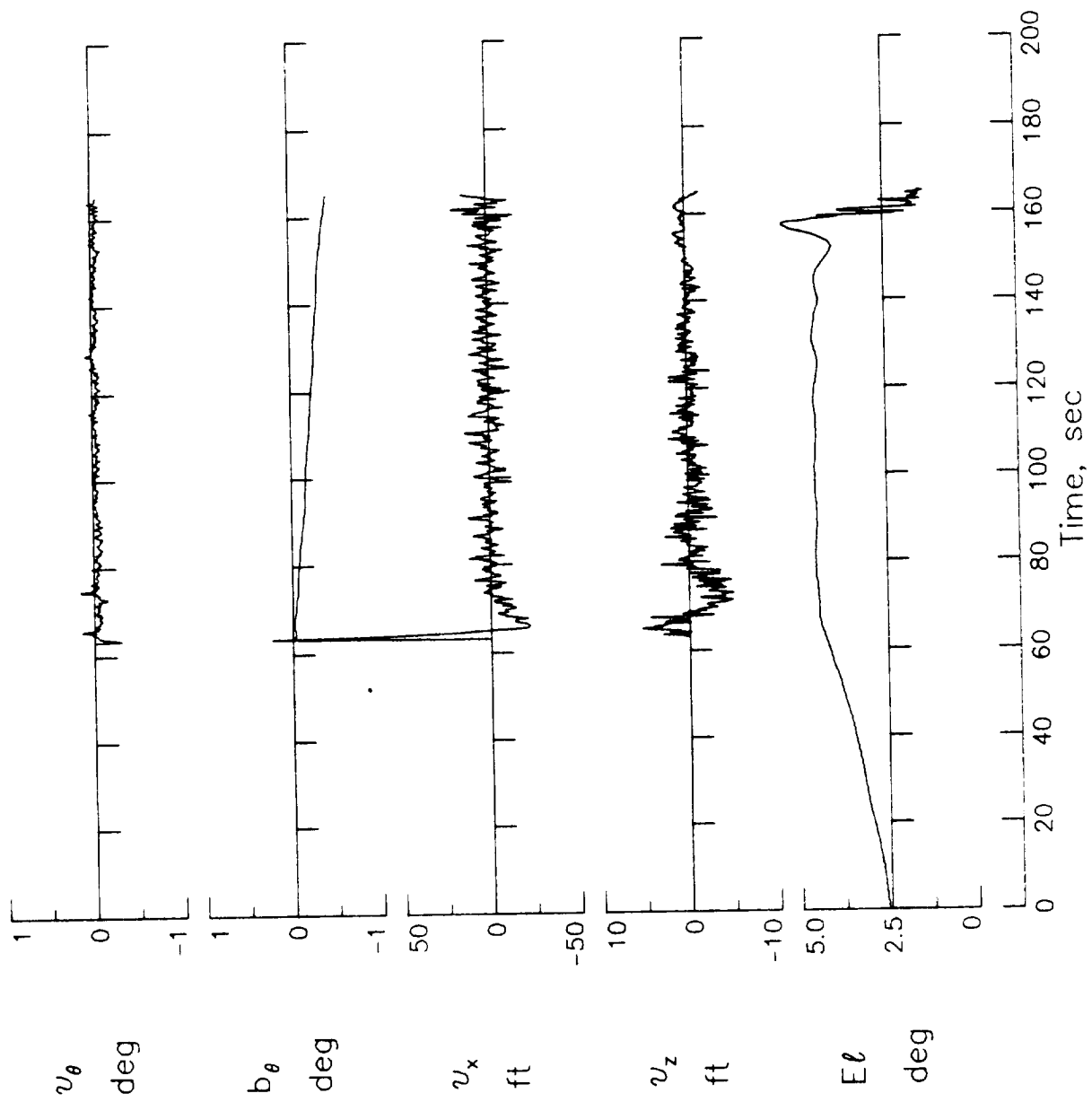


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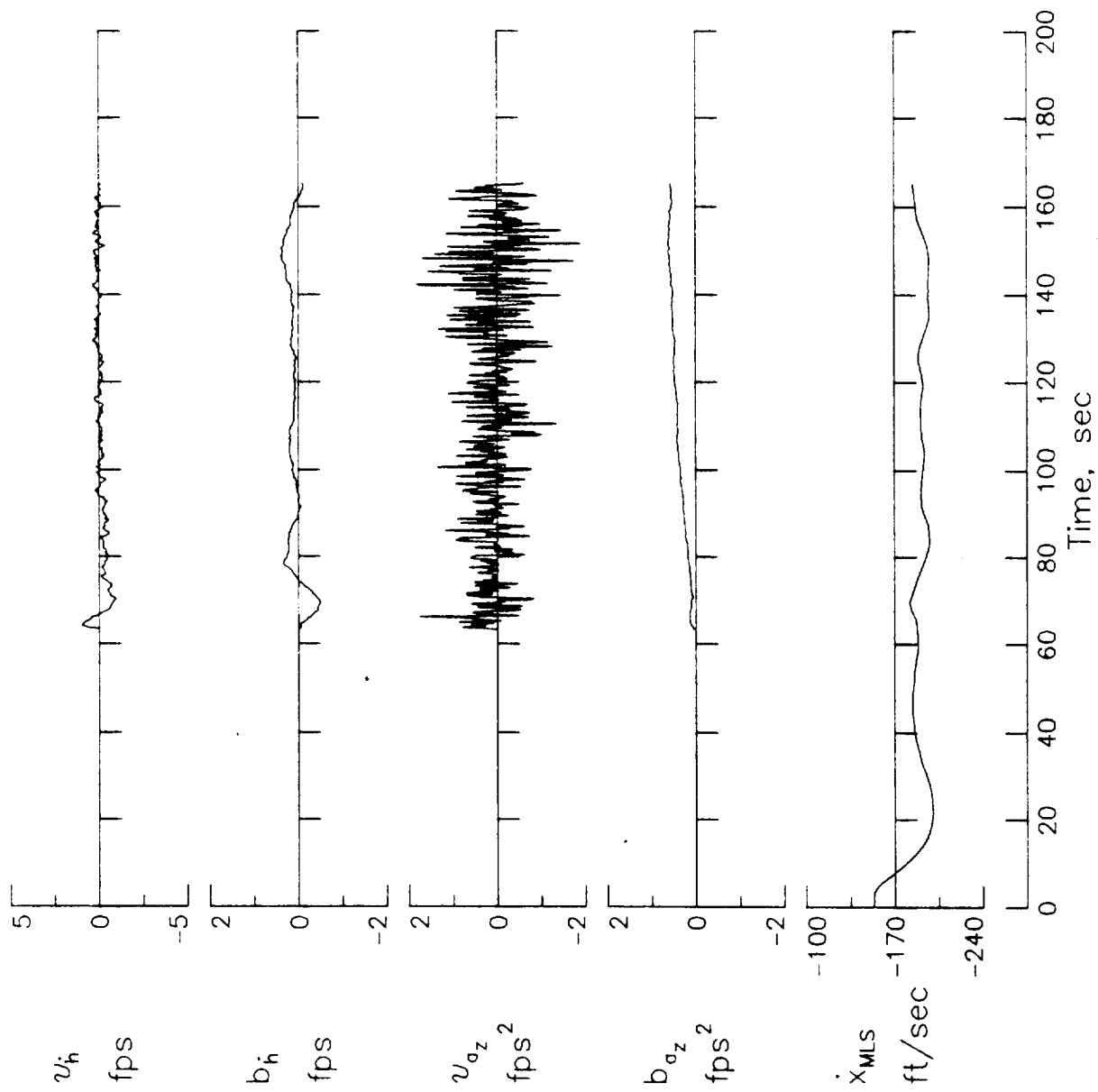


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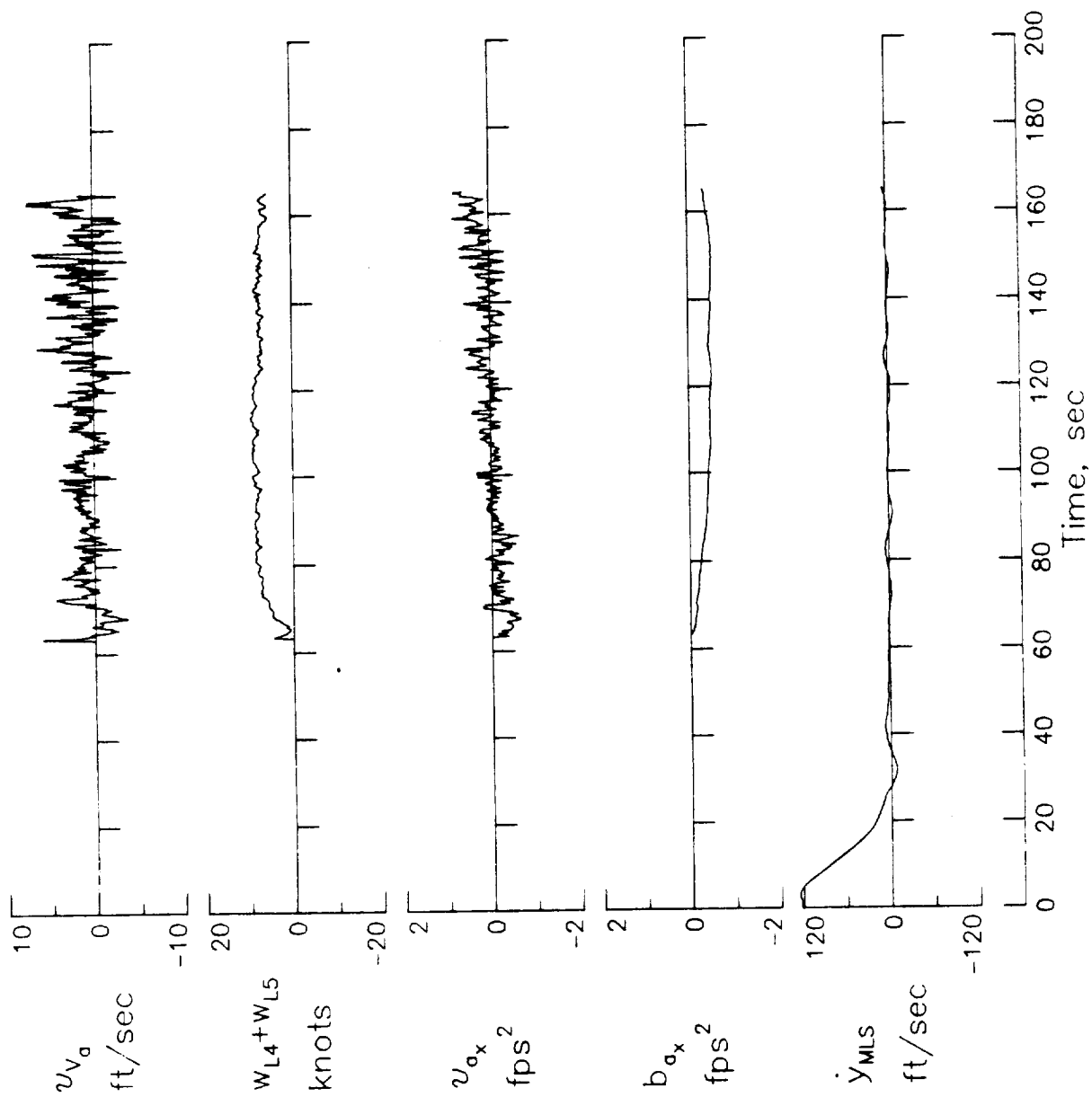


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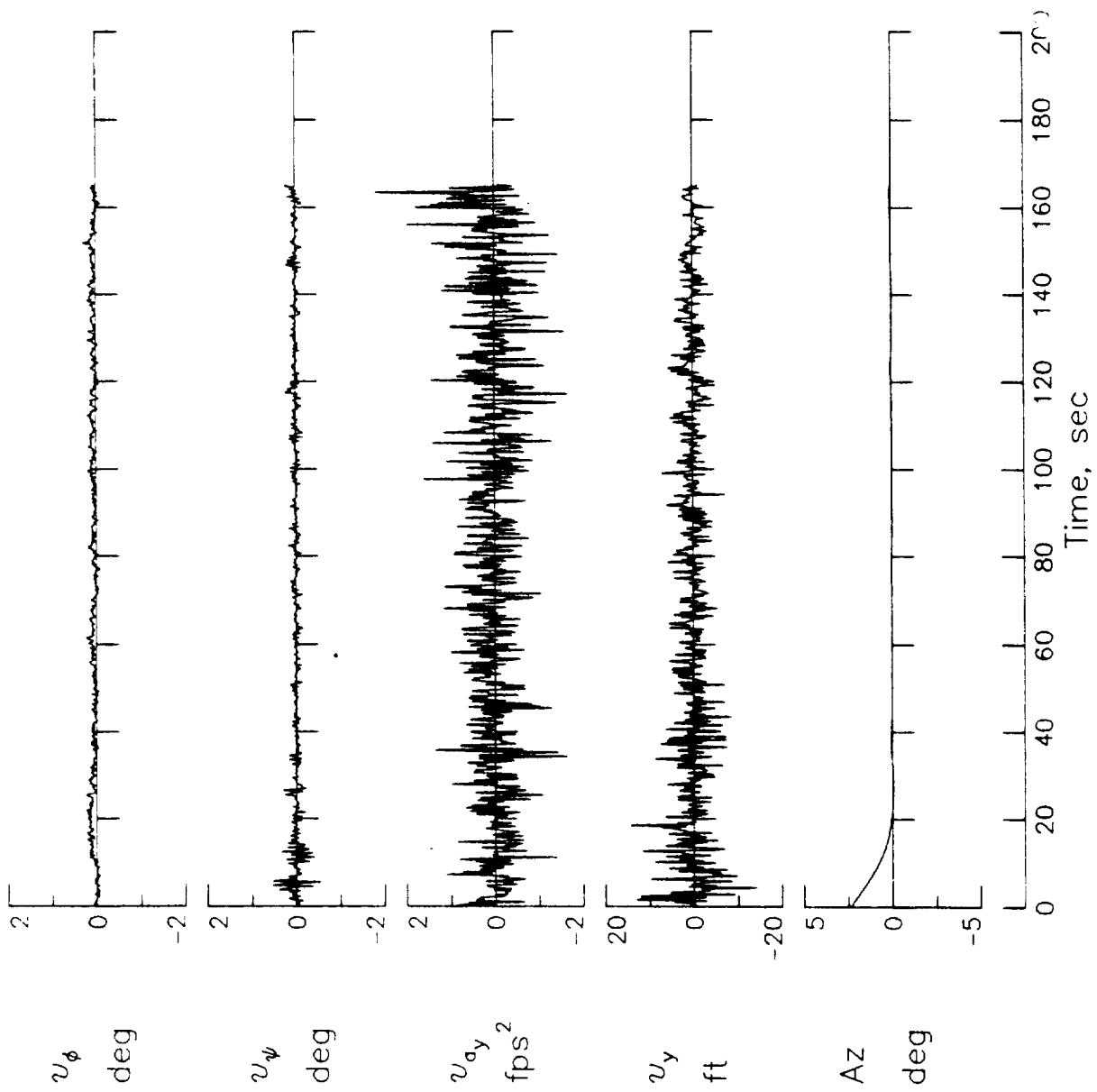


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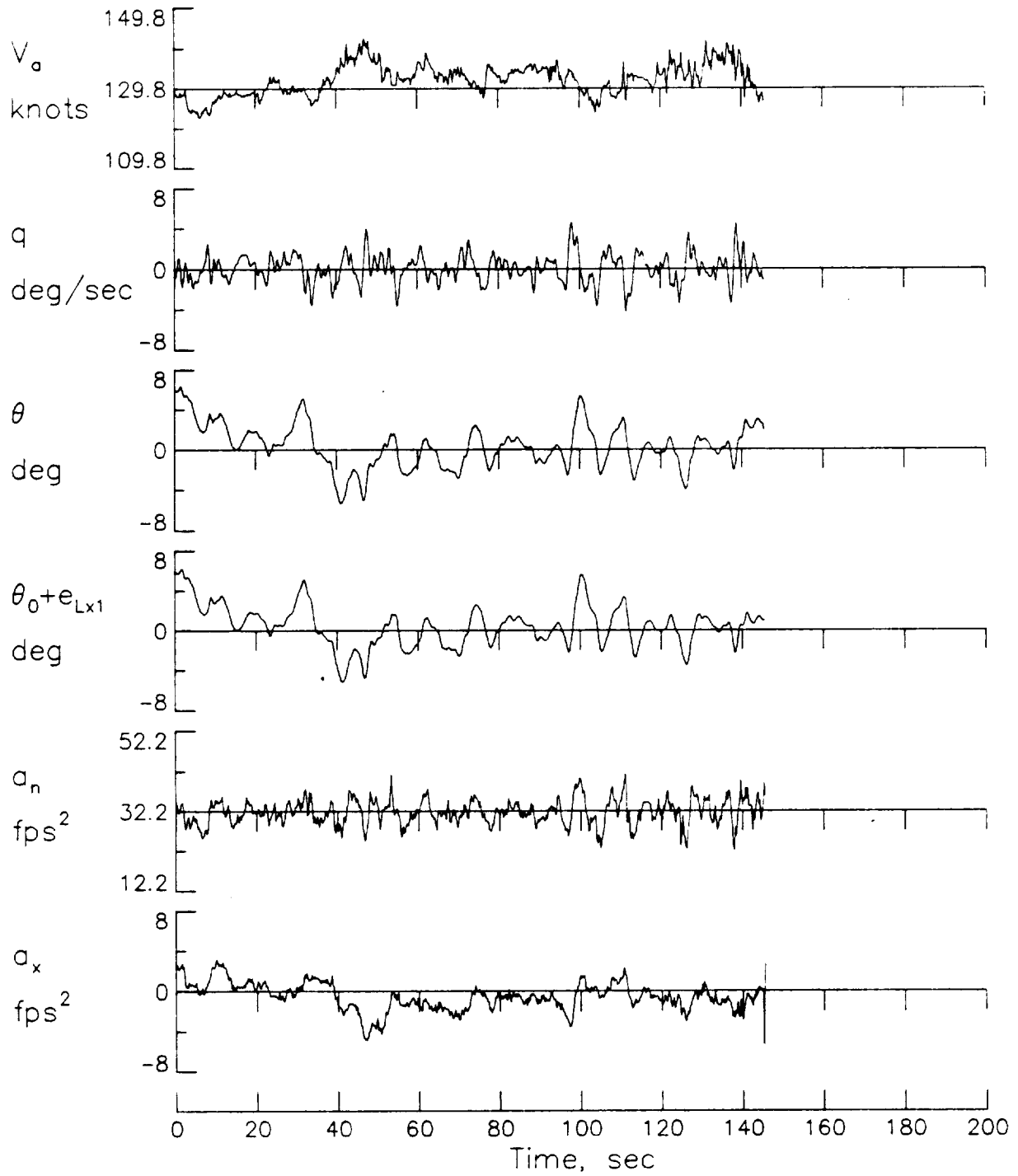


Figure 15. Flight Data for DIALS Flight Test
R357, Run 7

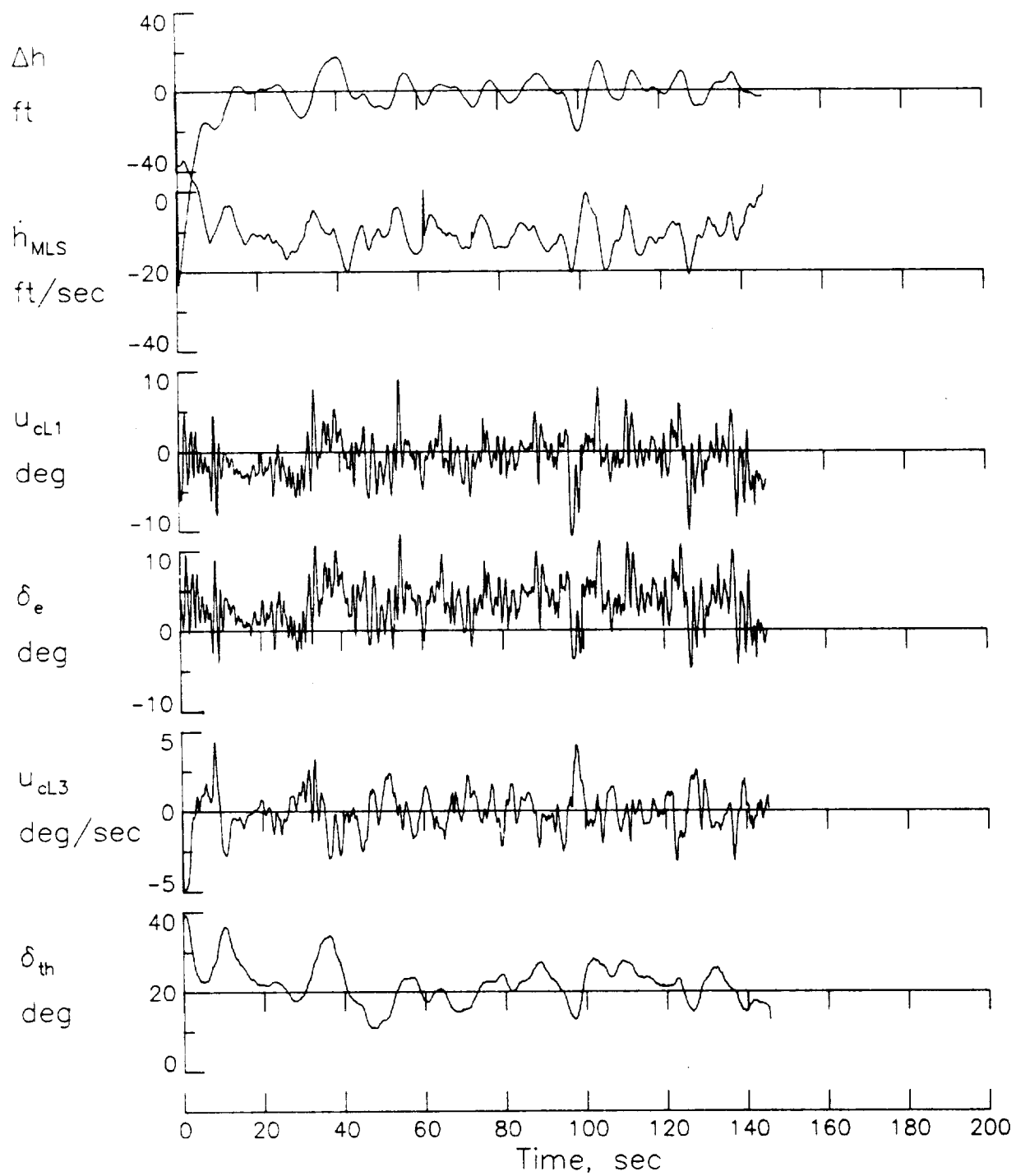


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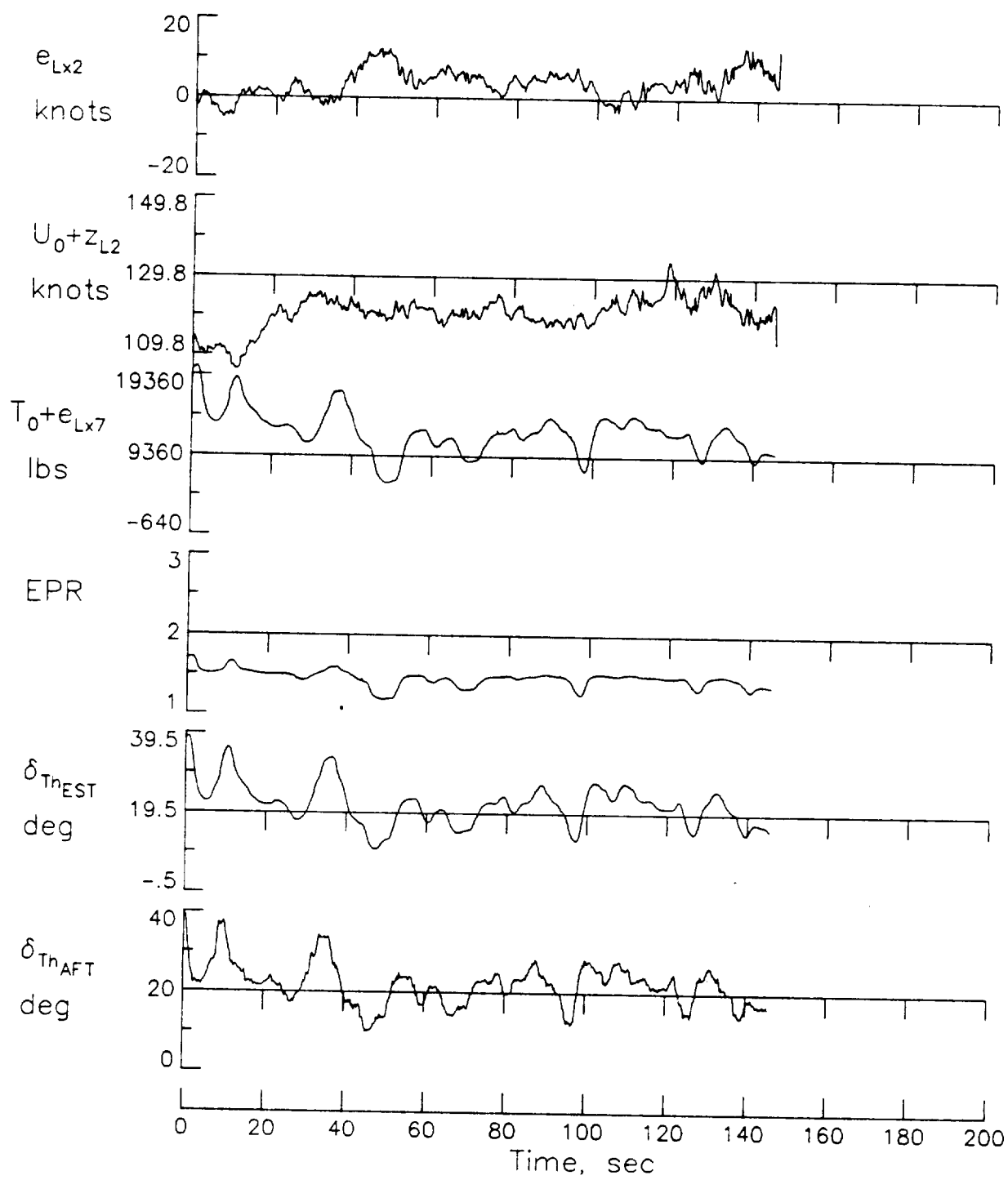


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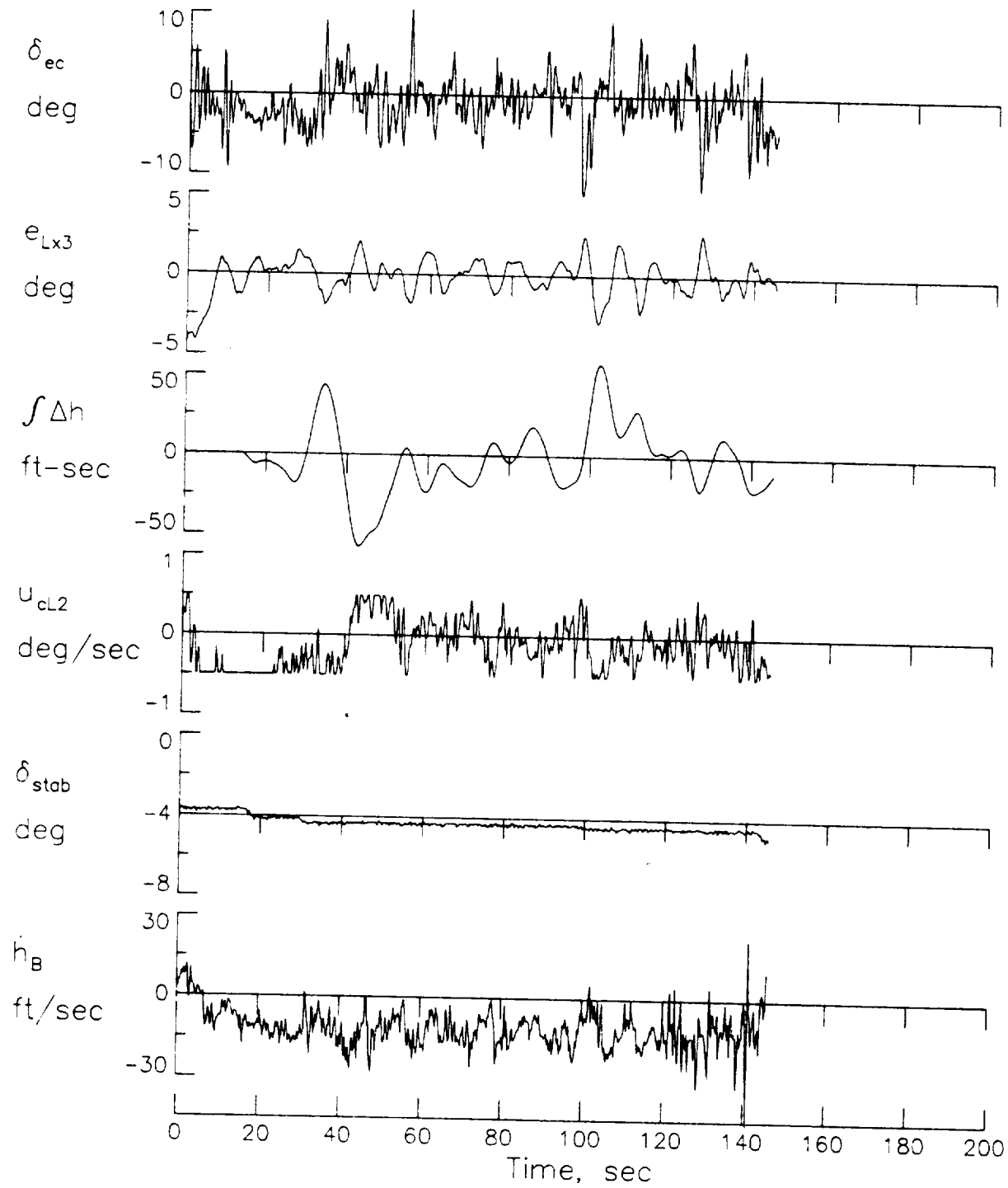


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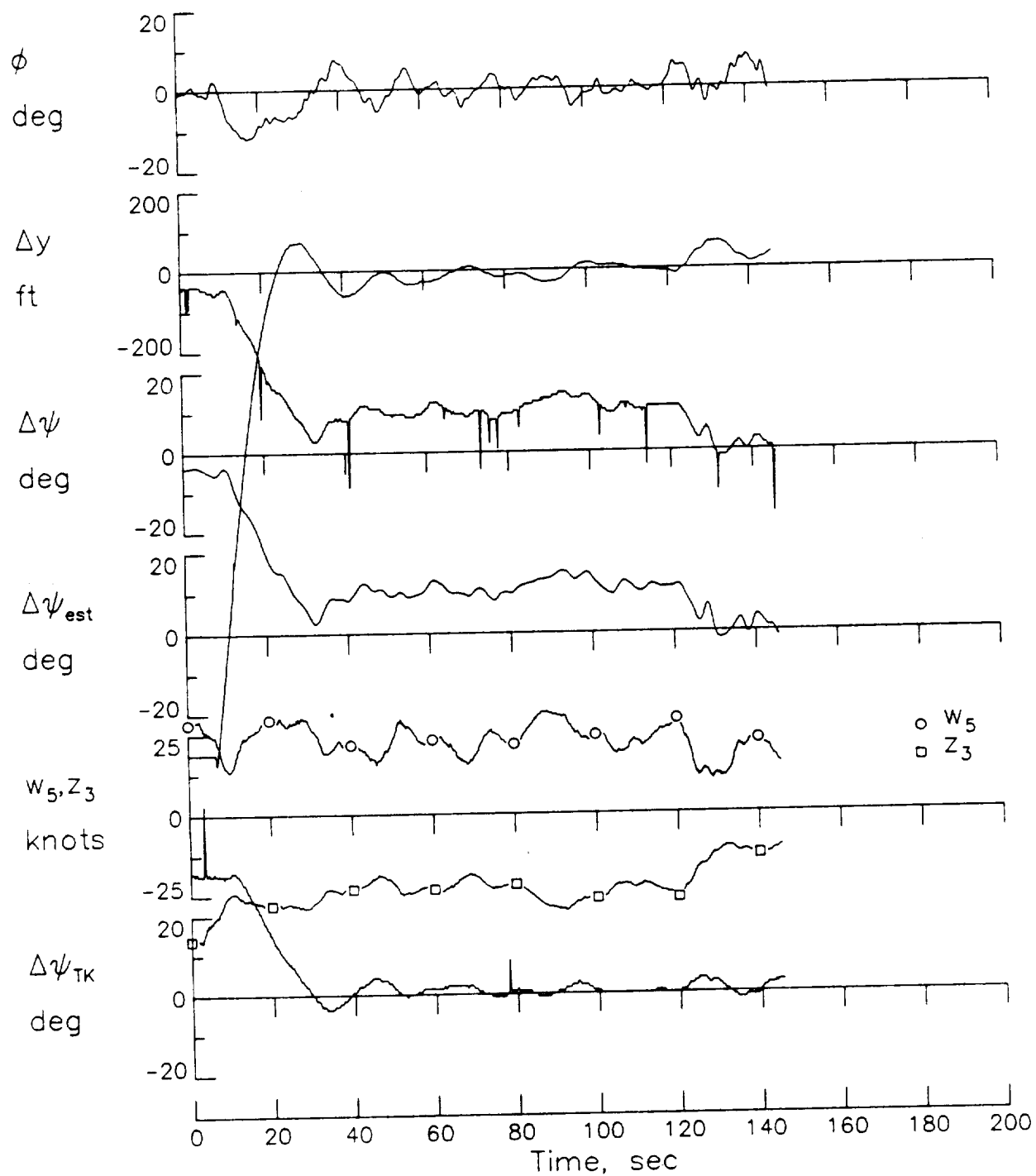


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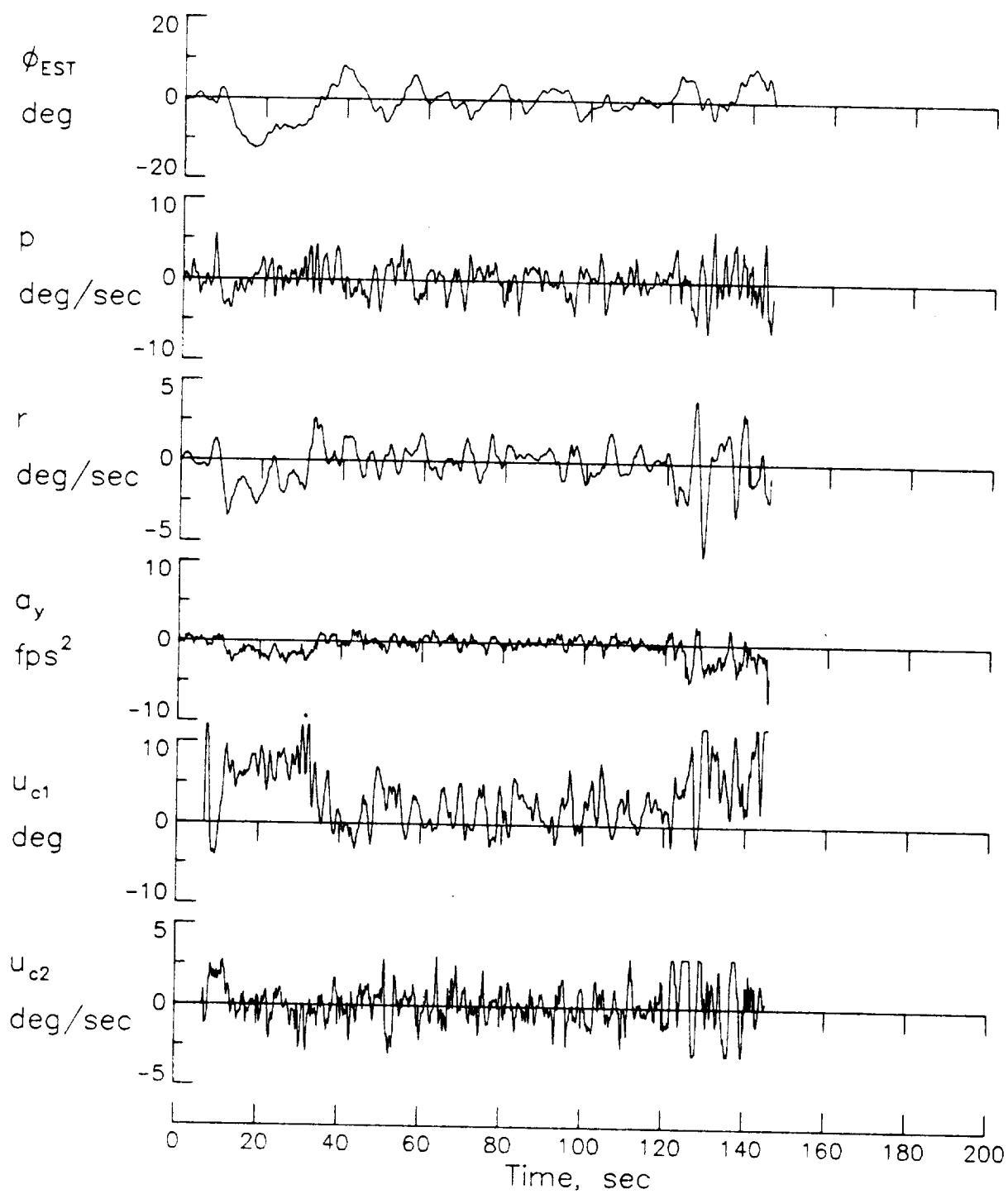


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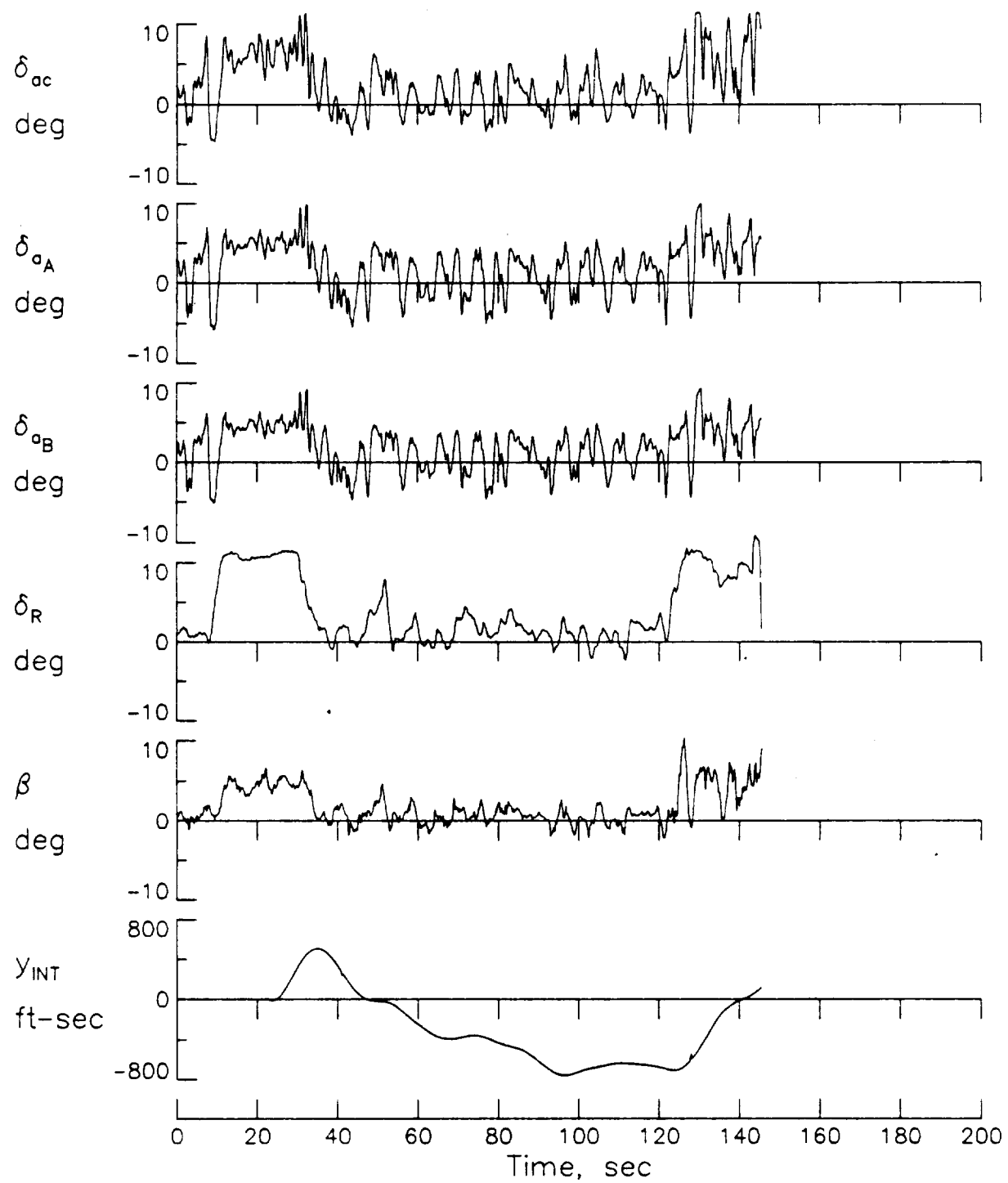


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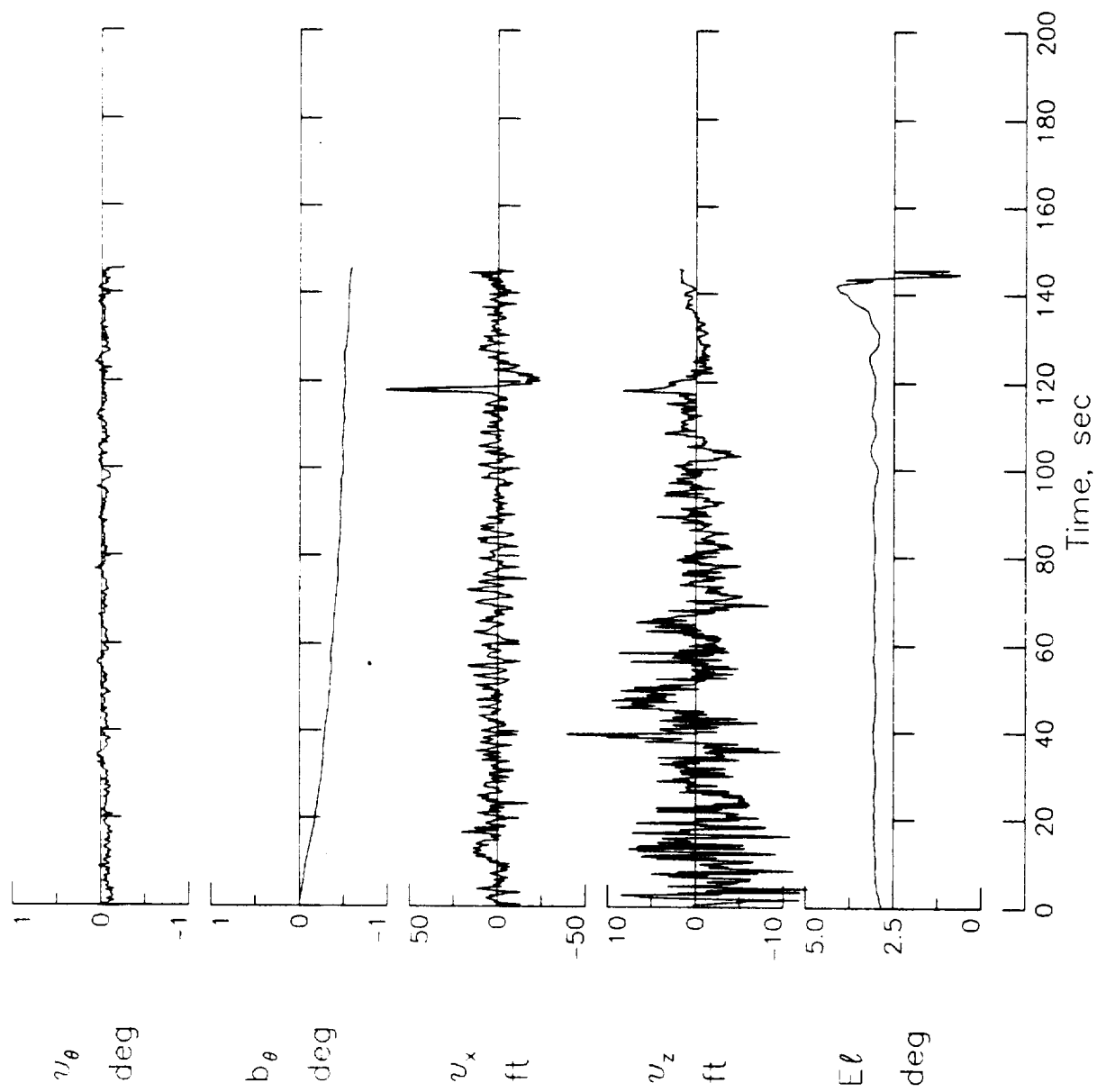


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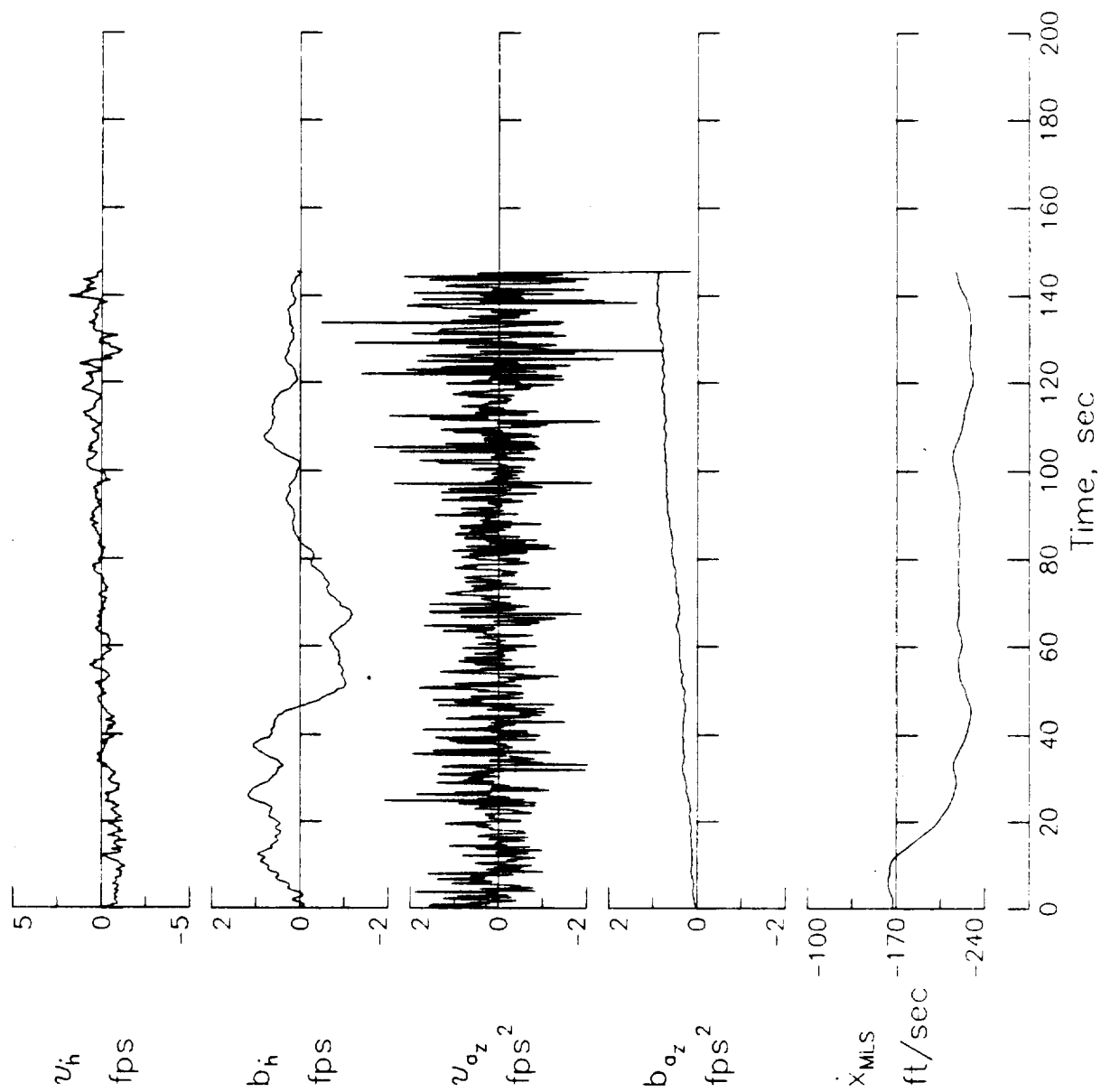


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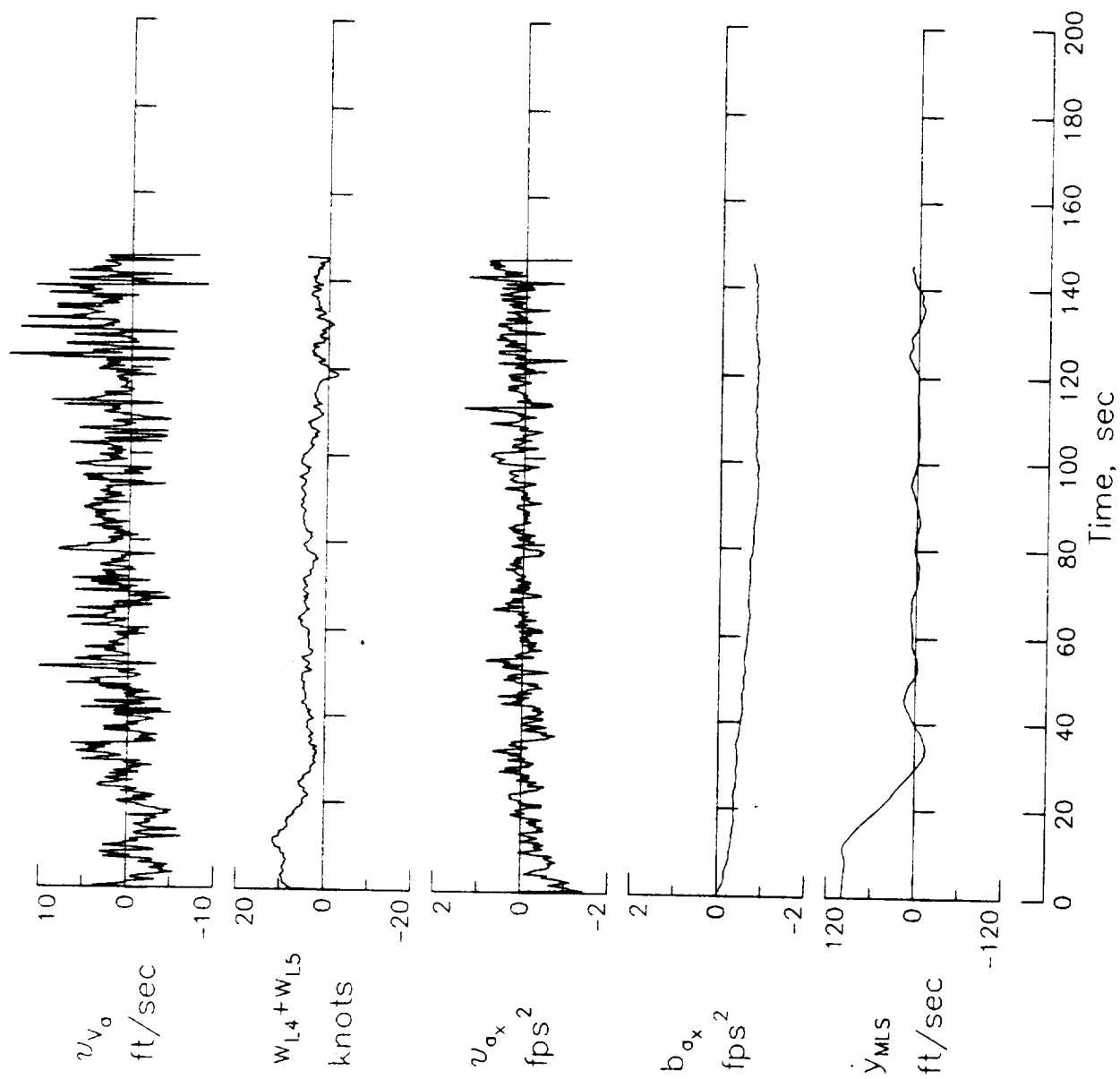


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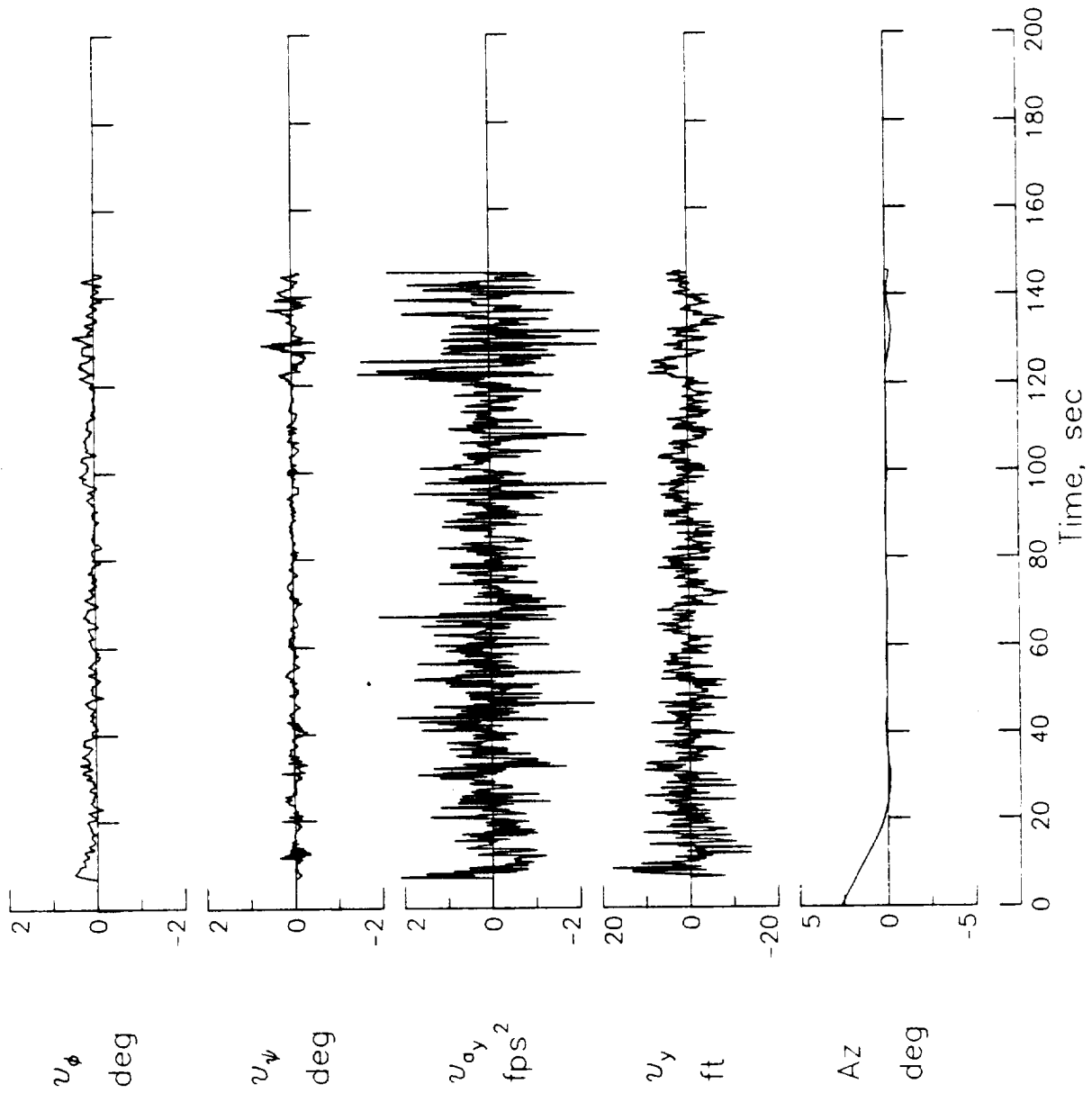


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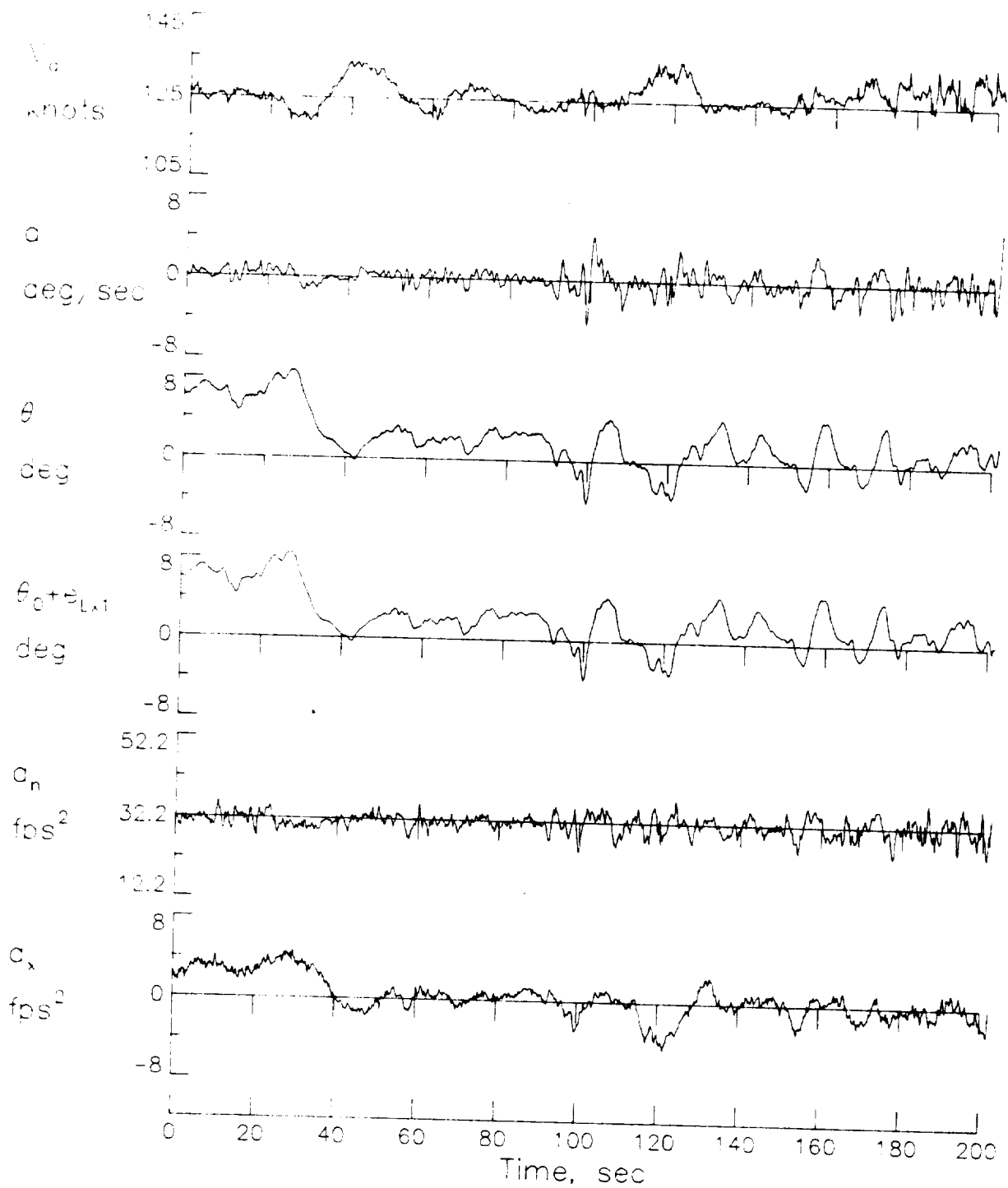


Figure 16. Flight Data for DIALS Flight Test
R357, Run 7R1

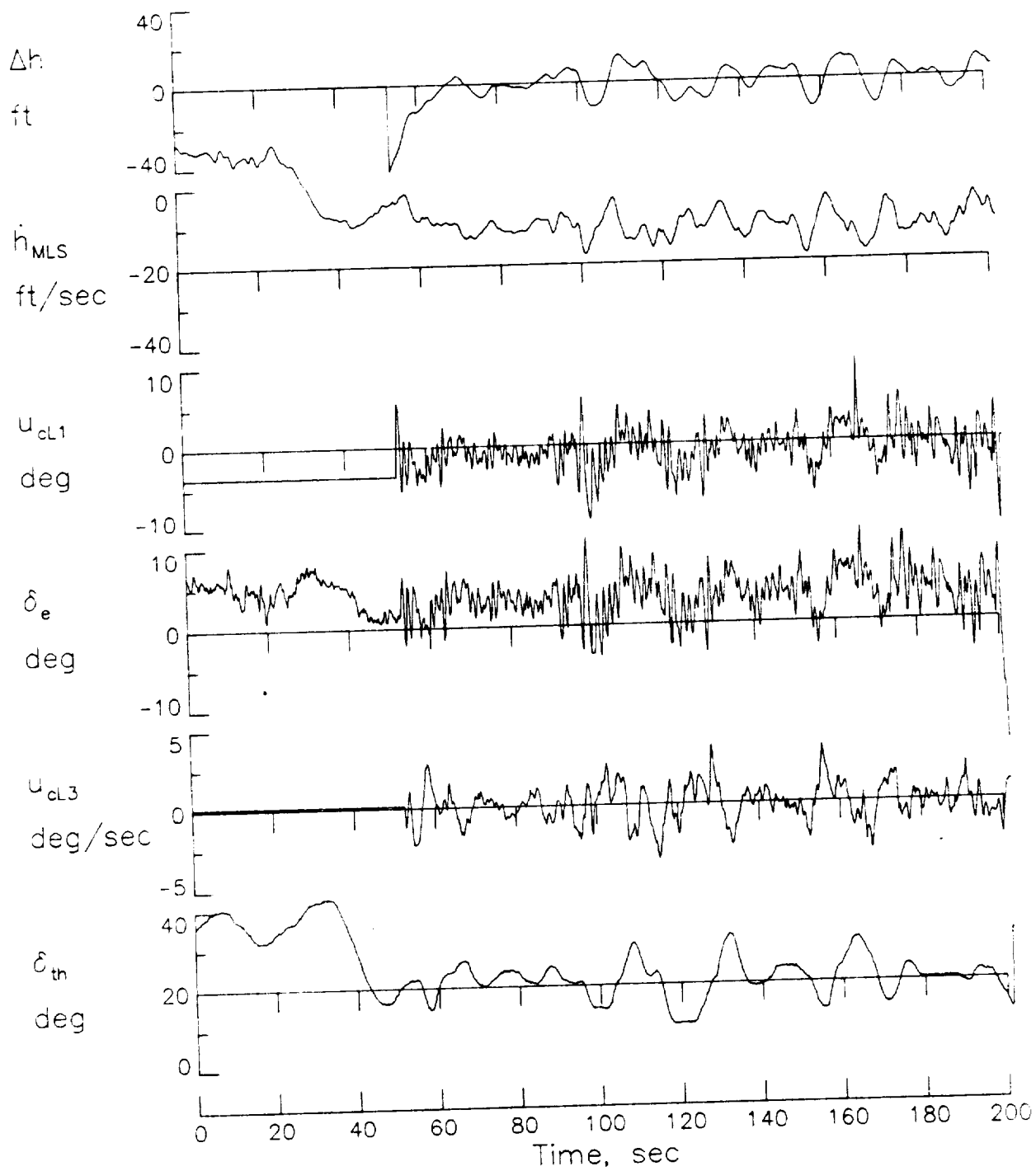


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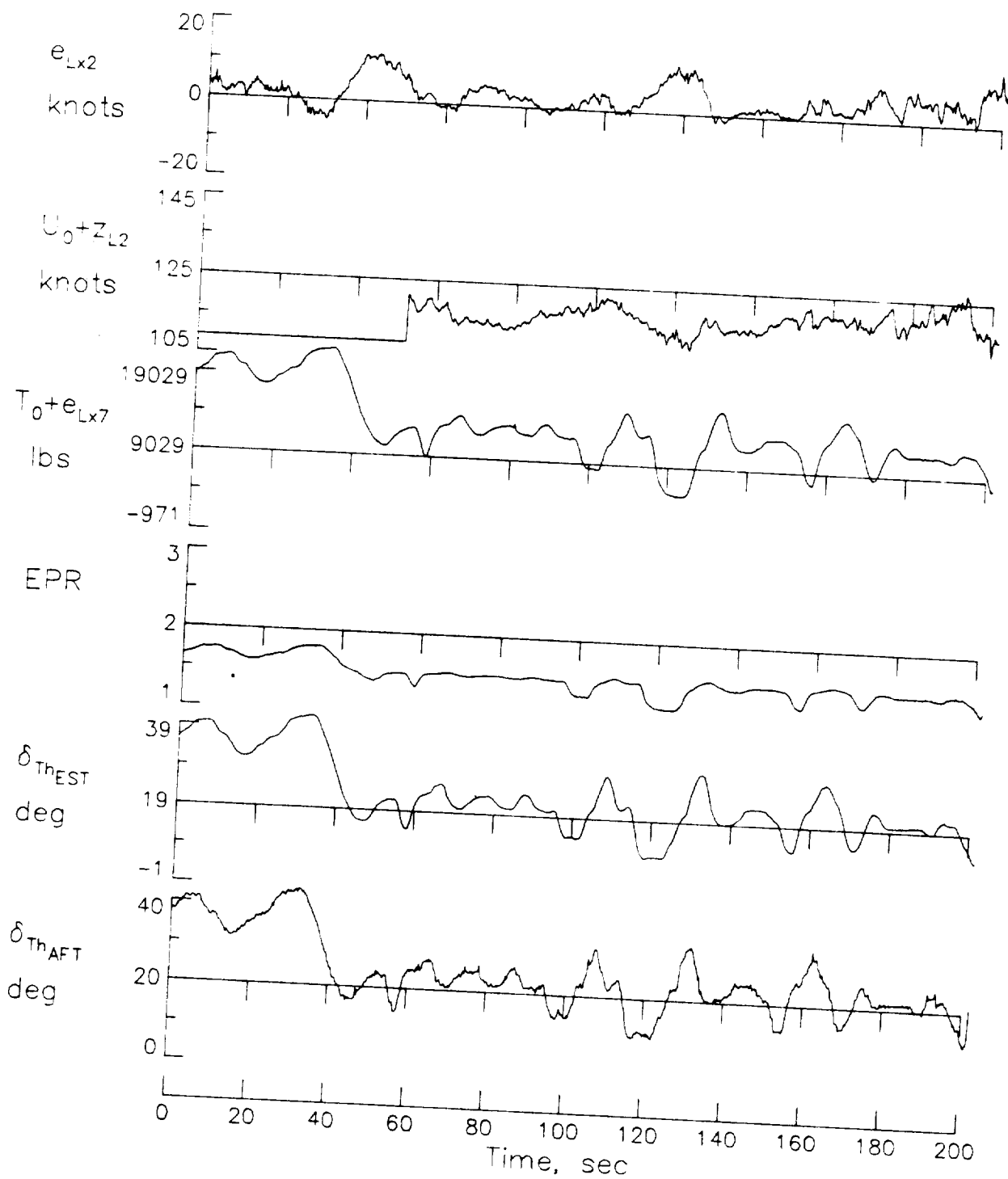


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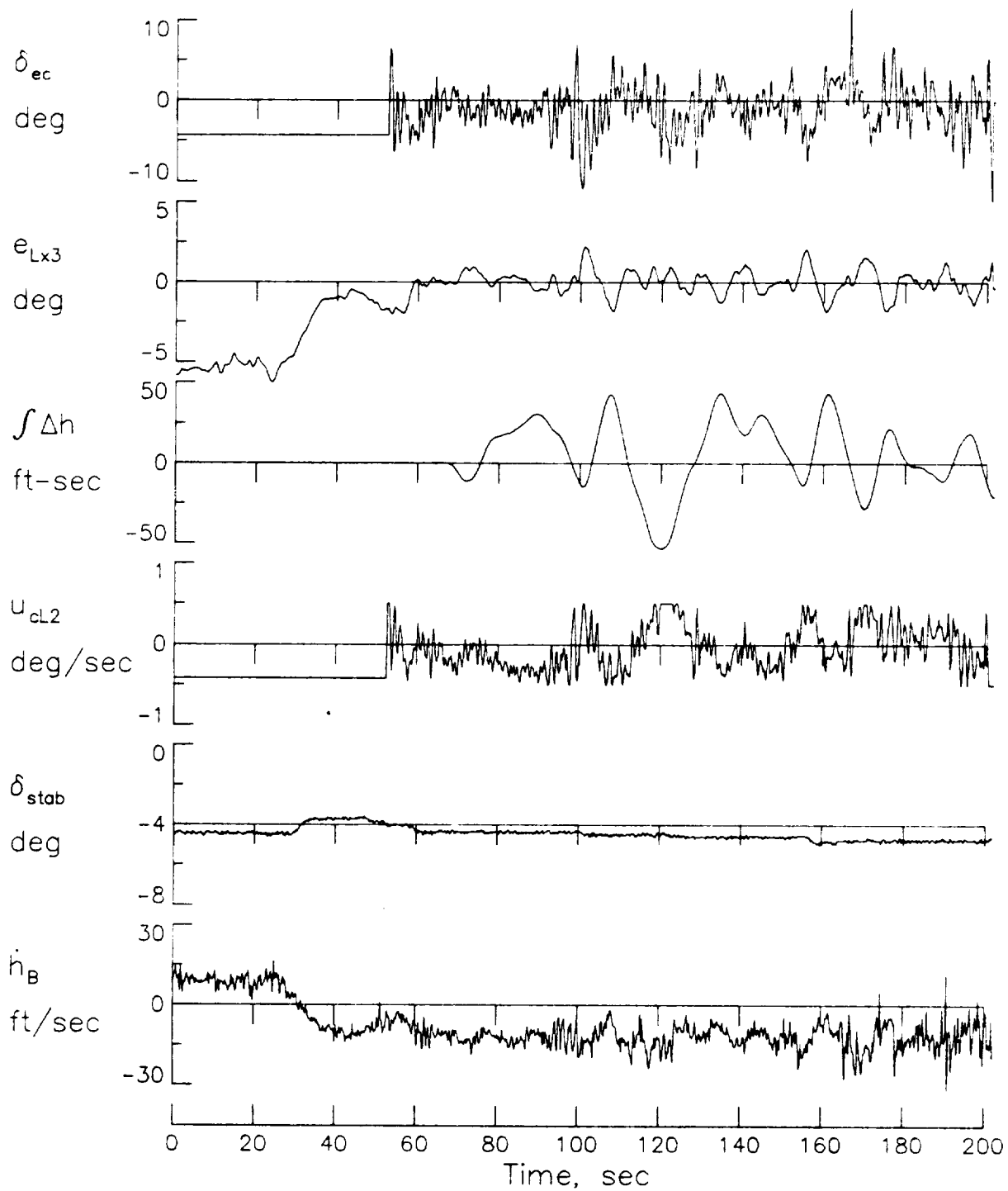


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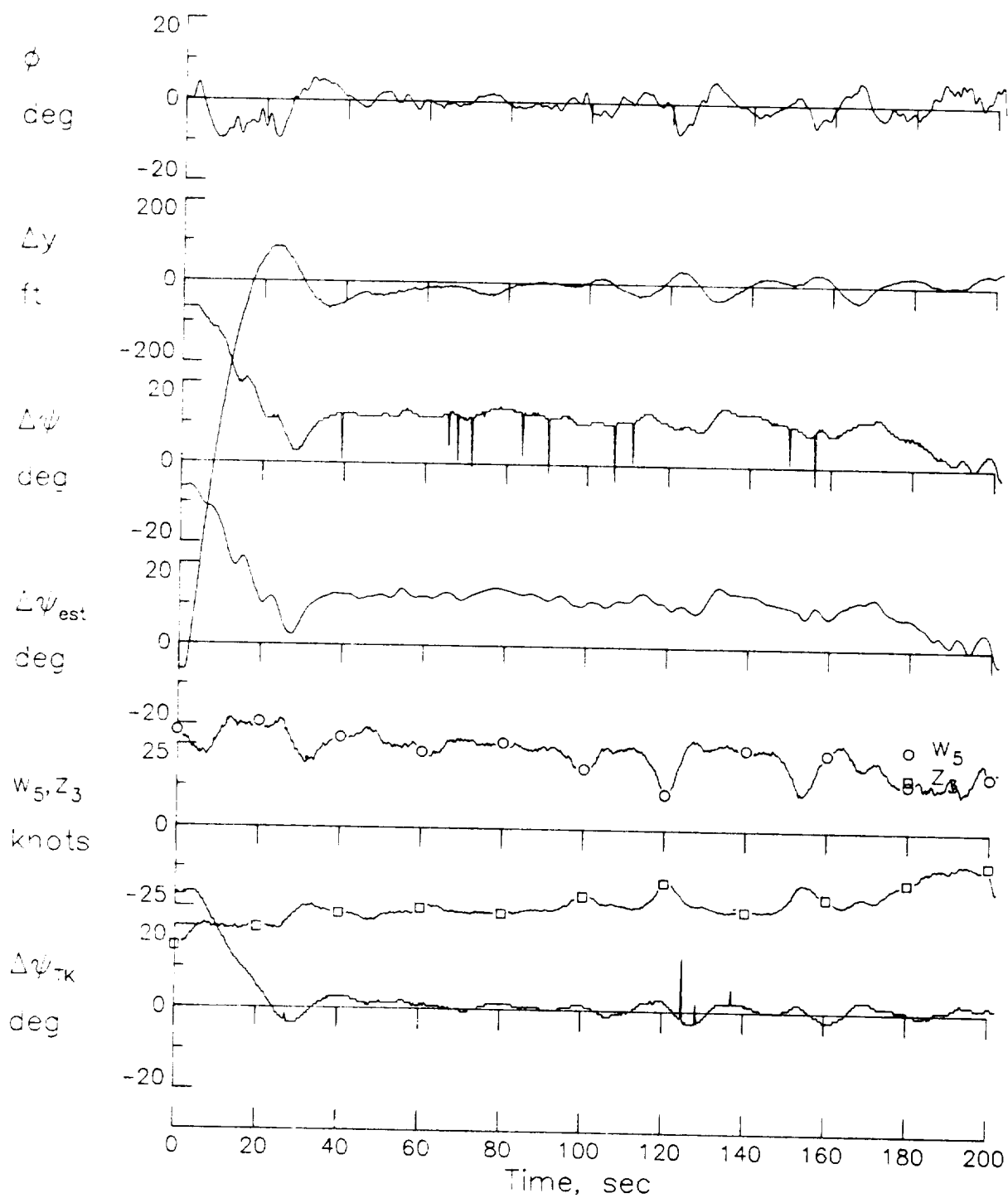


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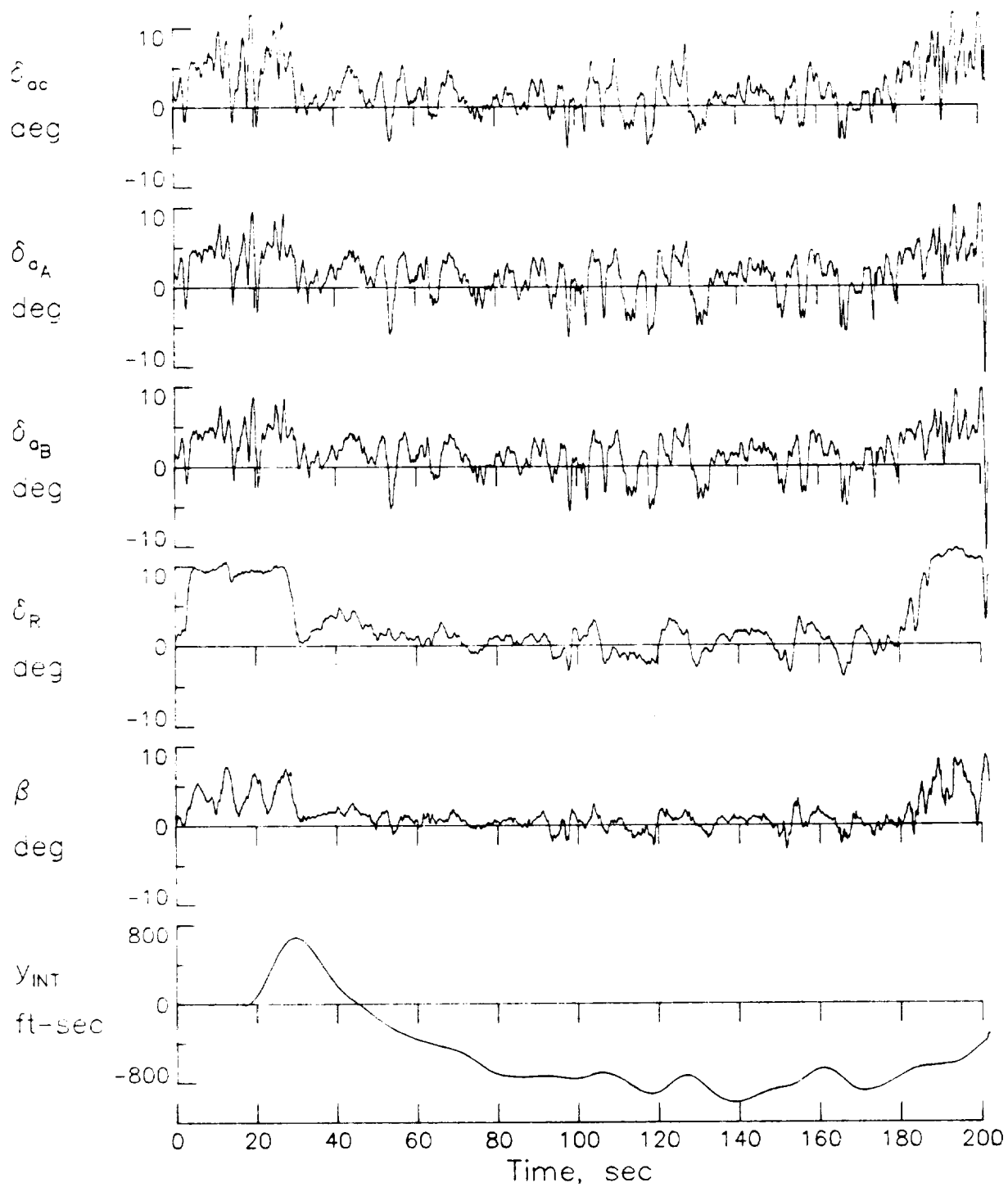


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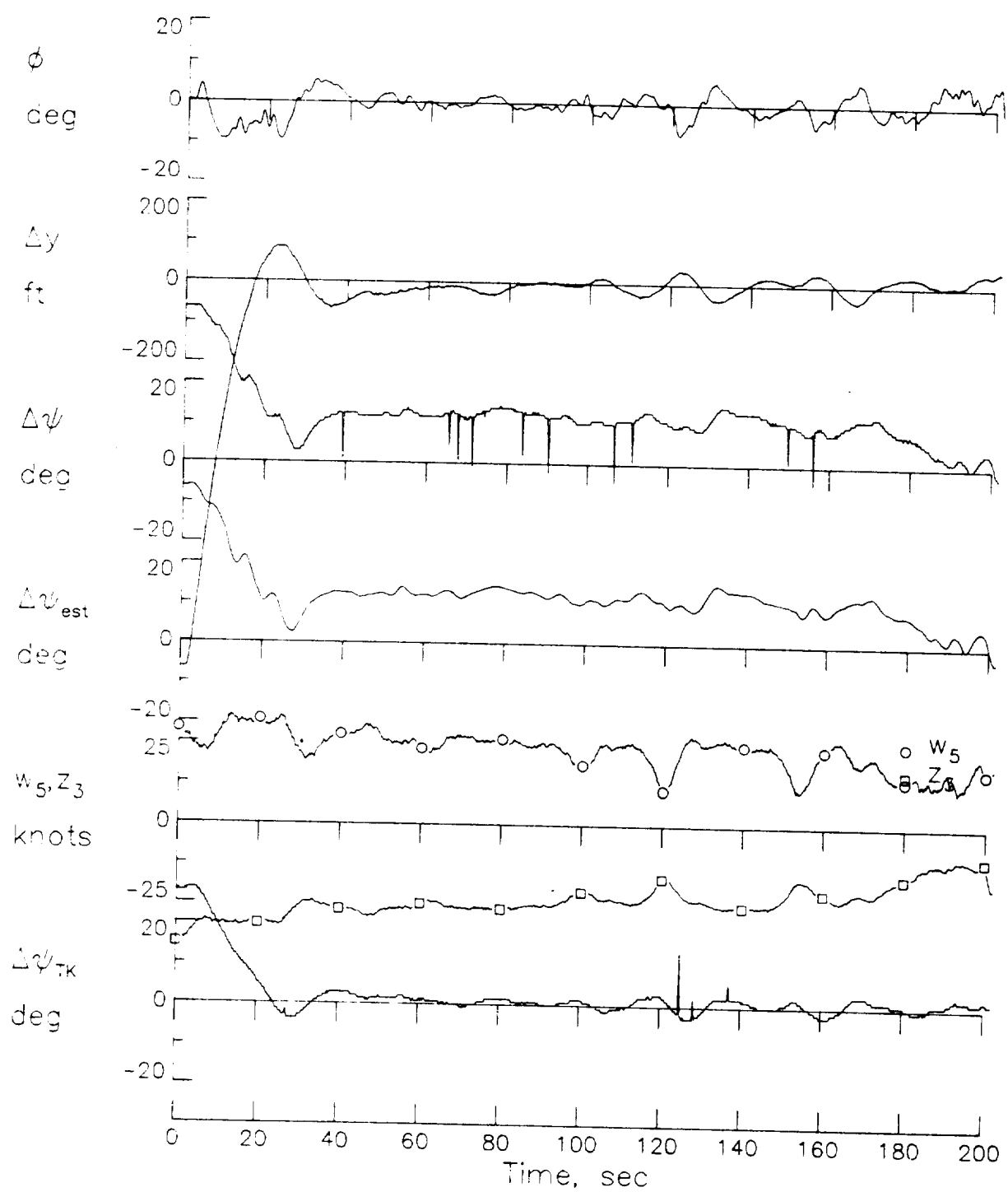


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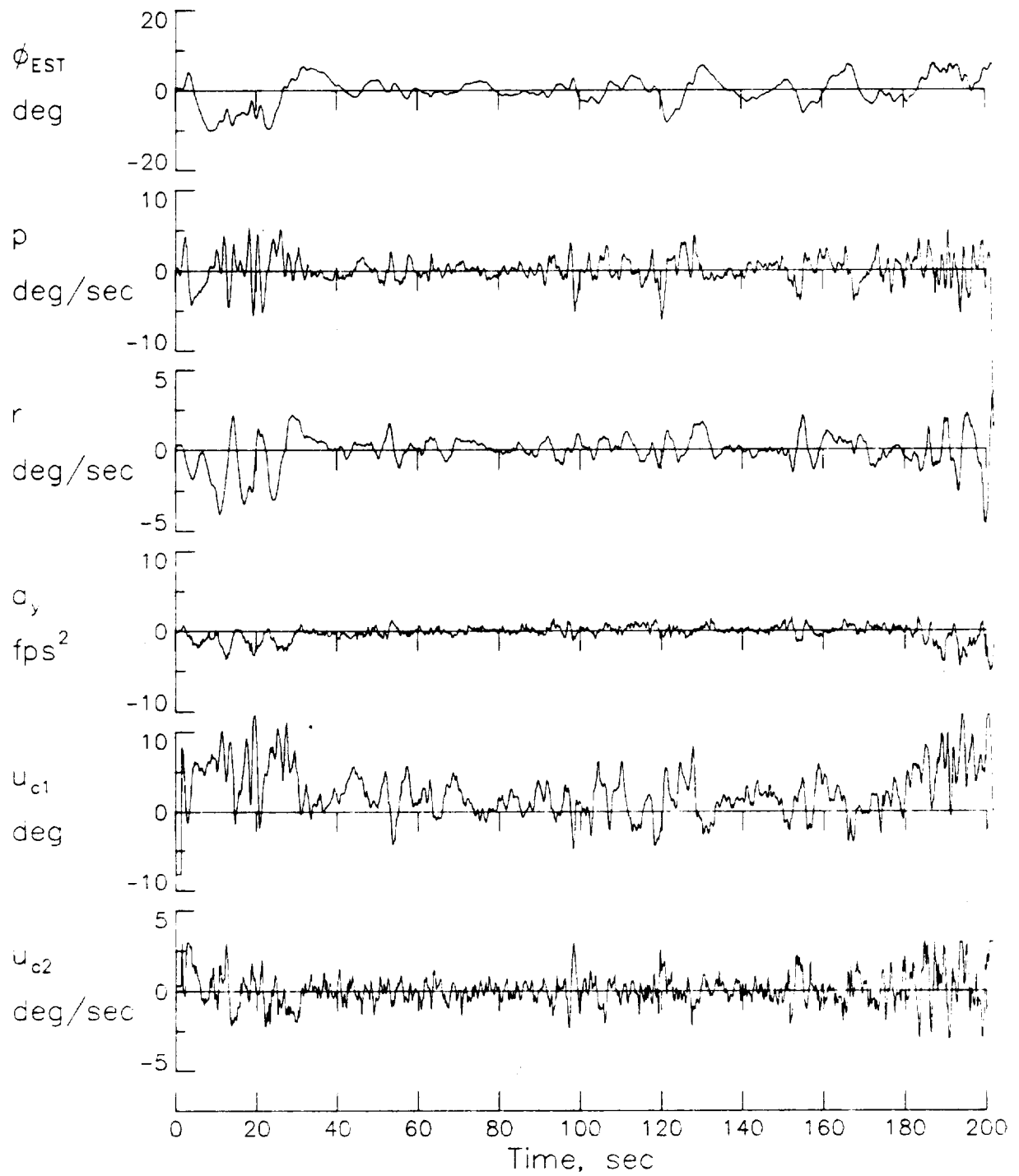


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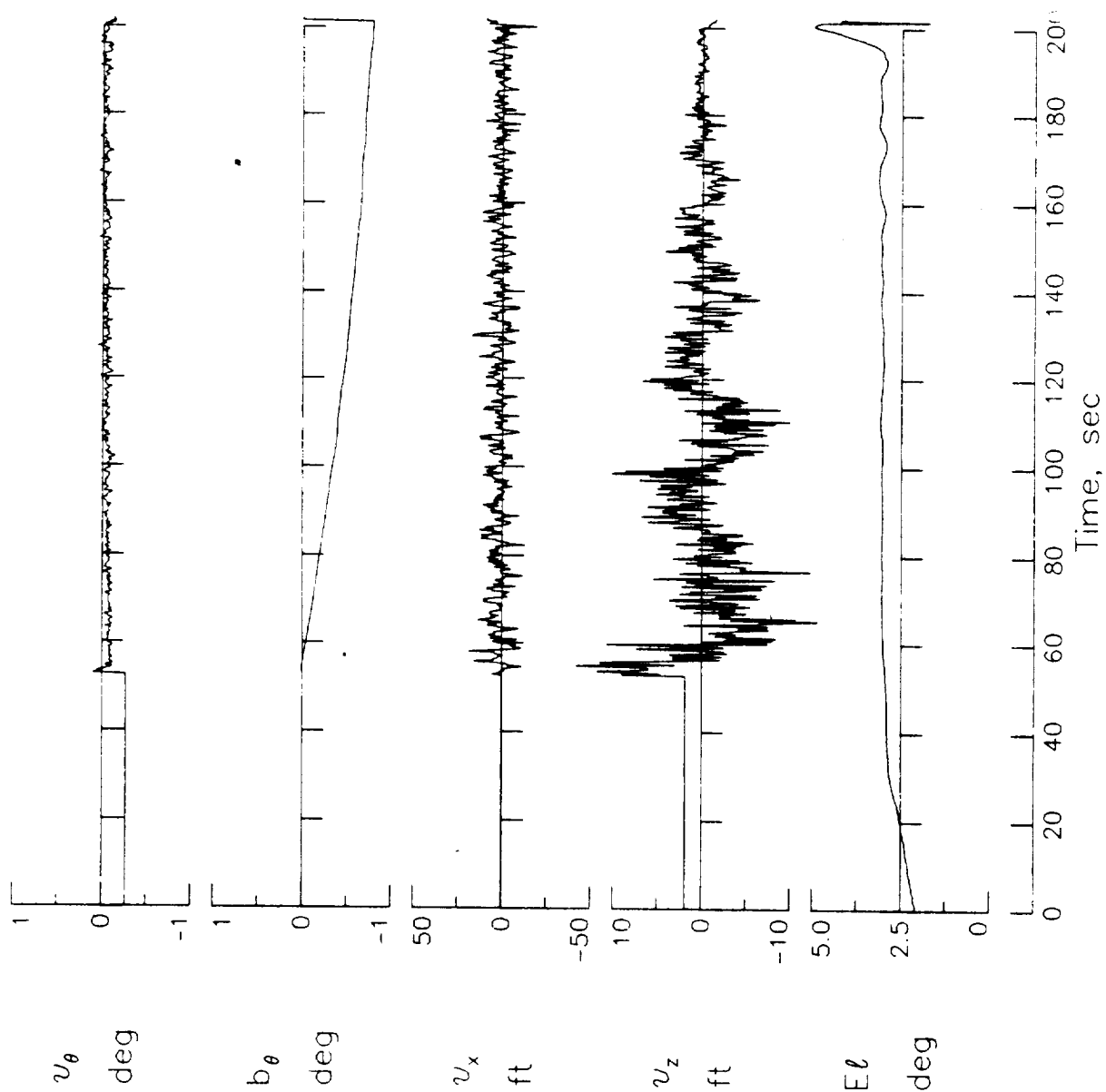


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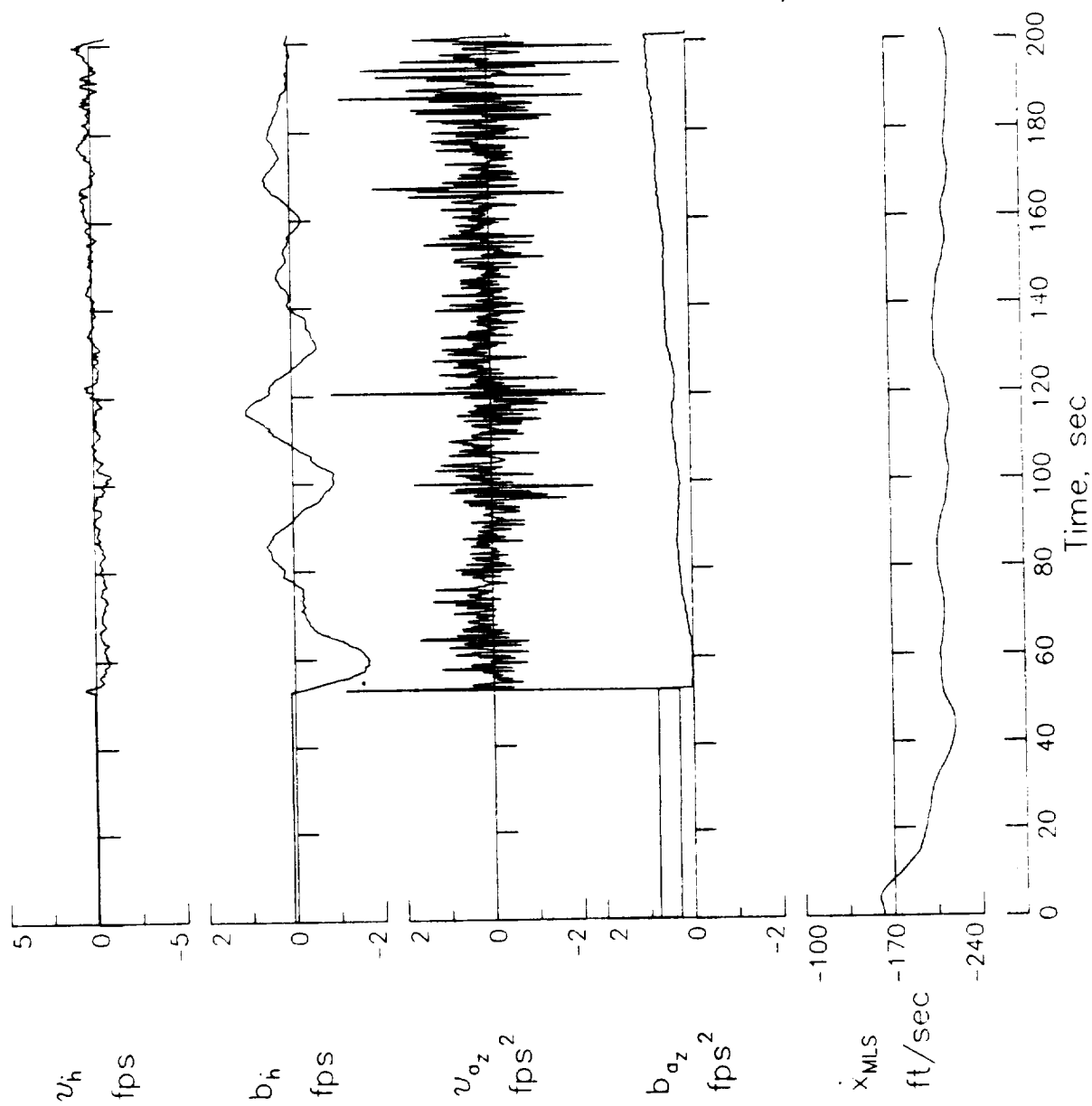


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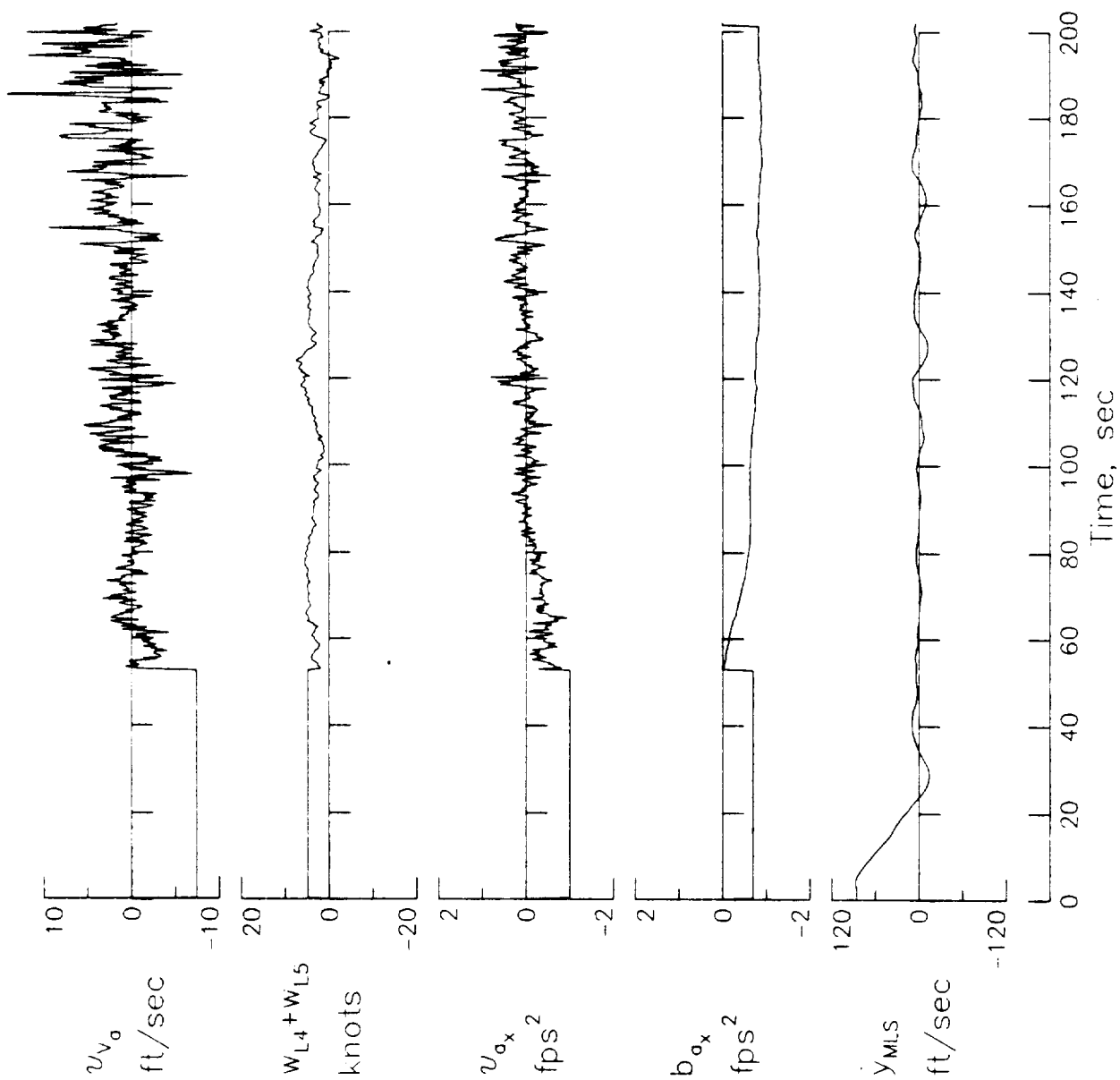


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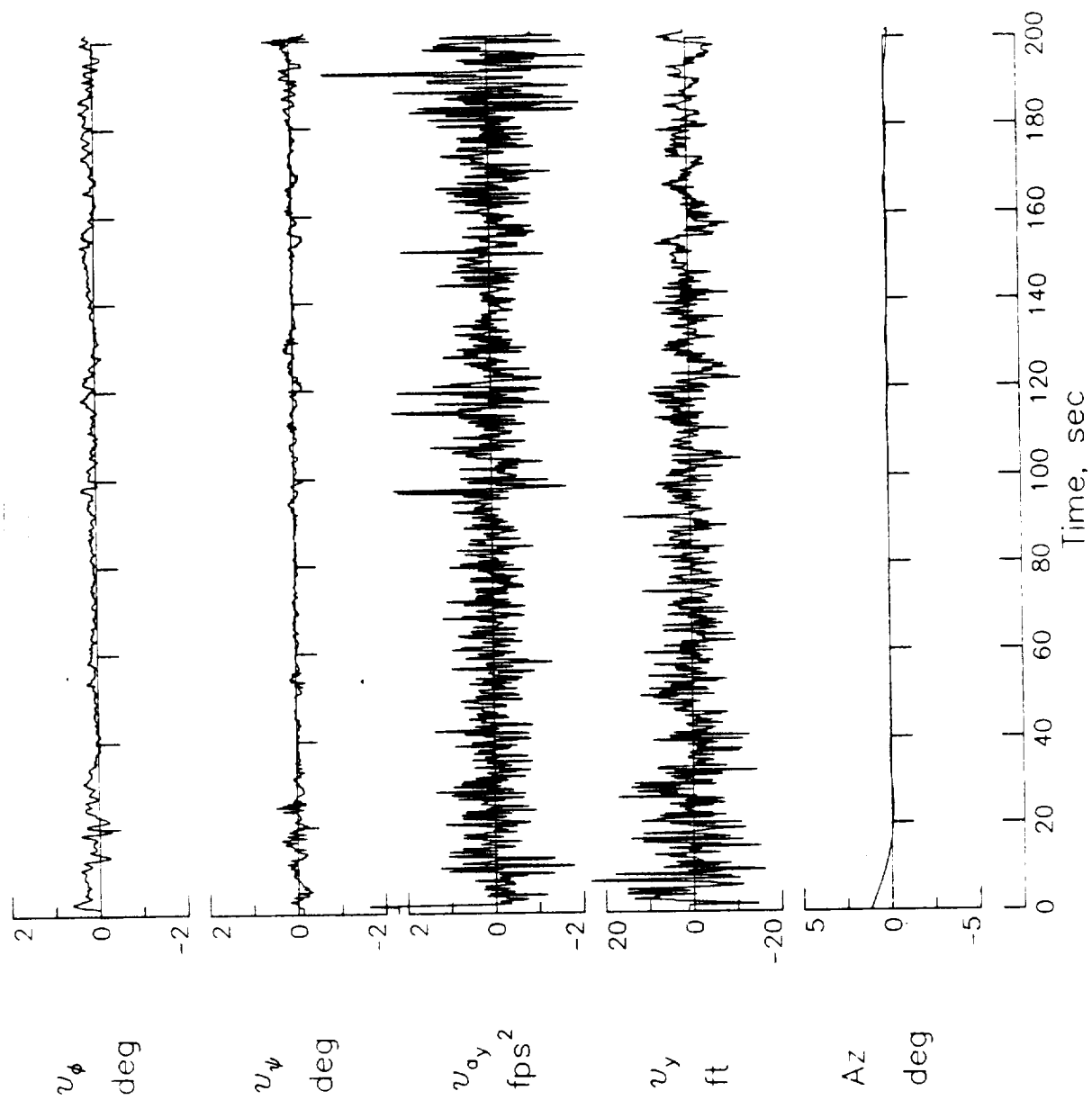


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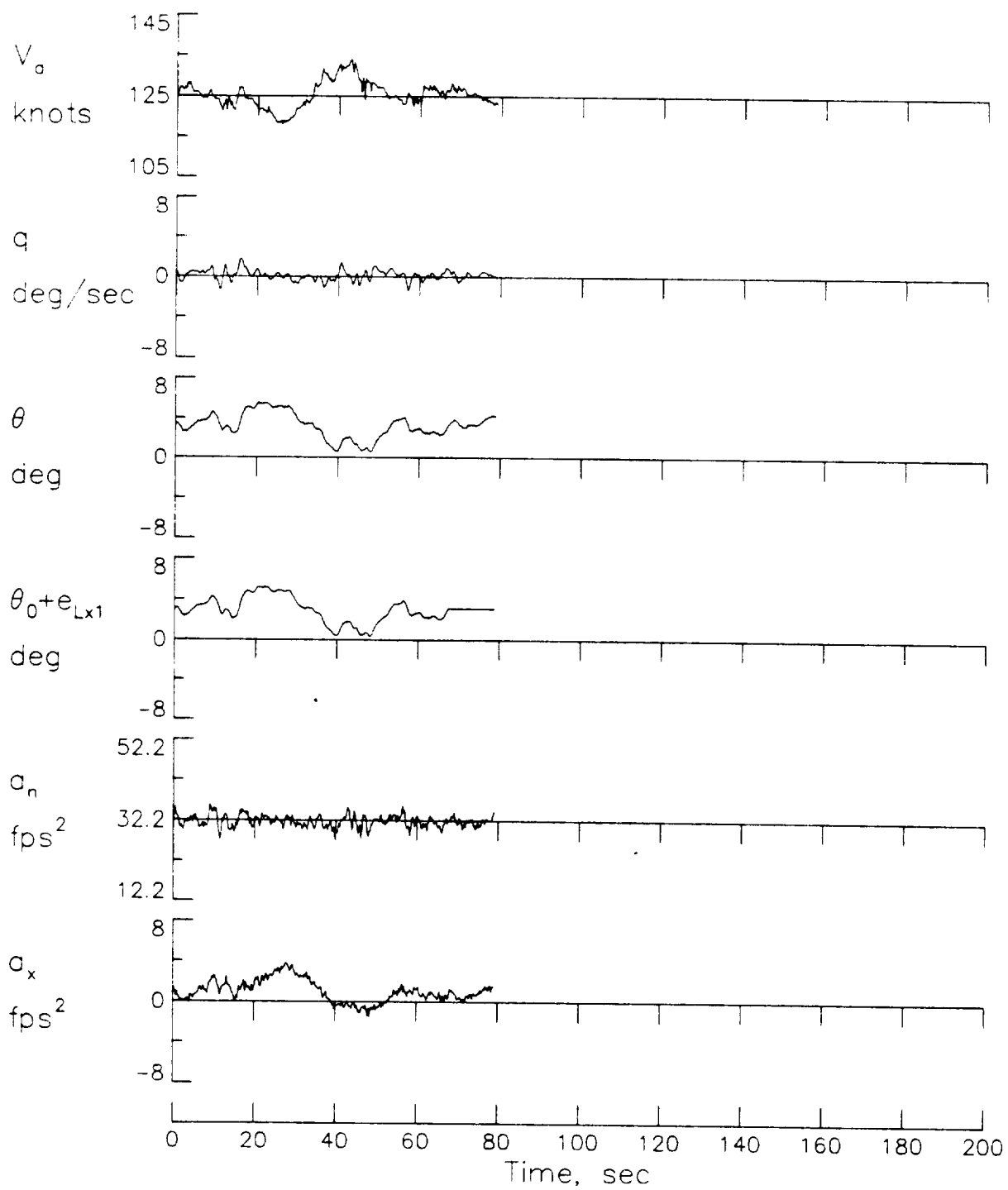


Figure 17. Flight Data for DIALS Flight Test
R357, Run 8

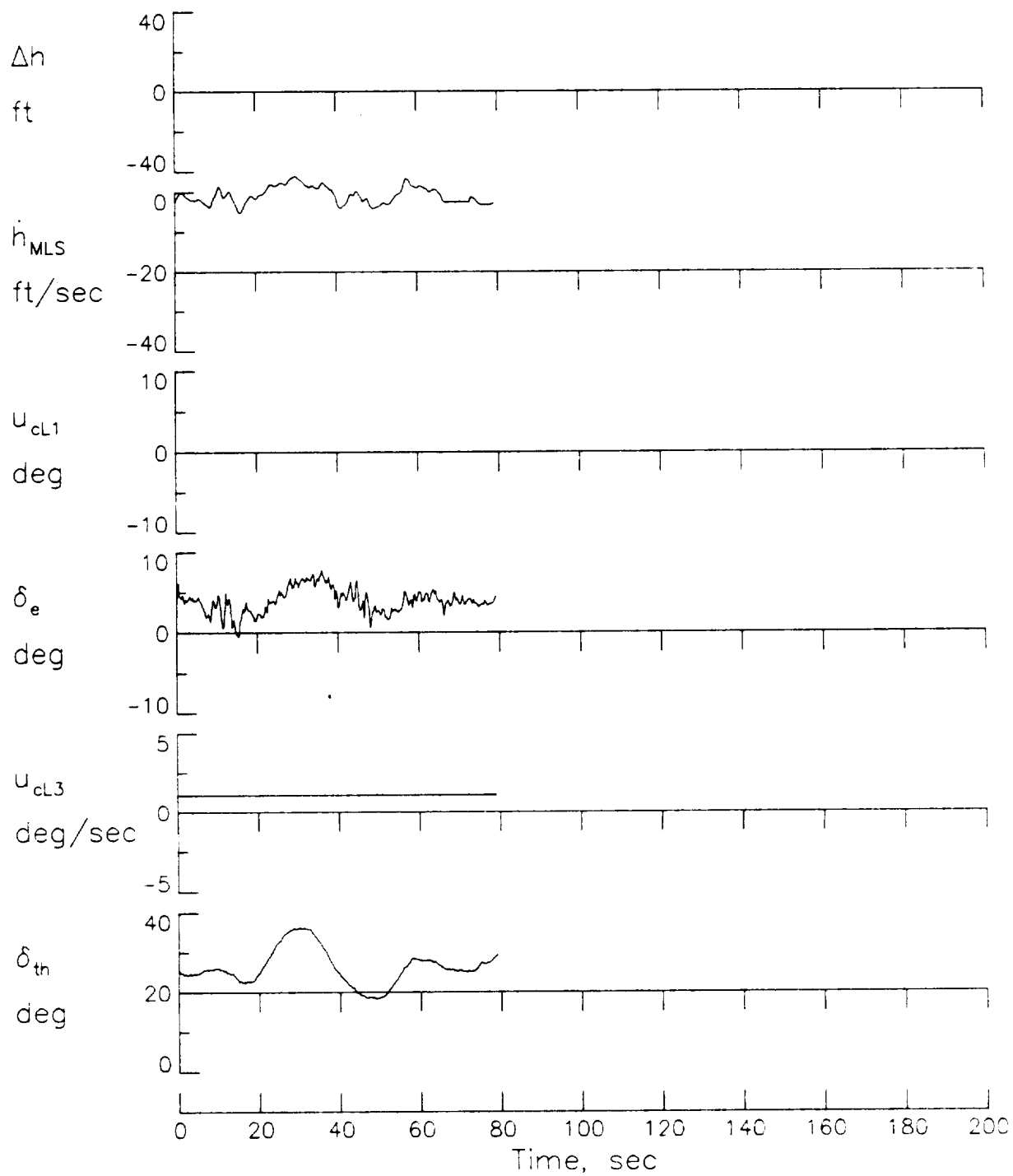


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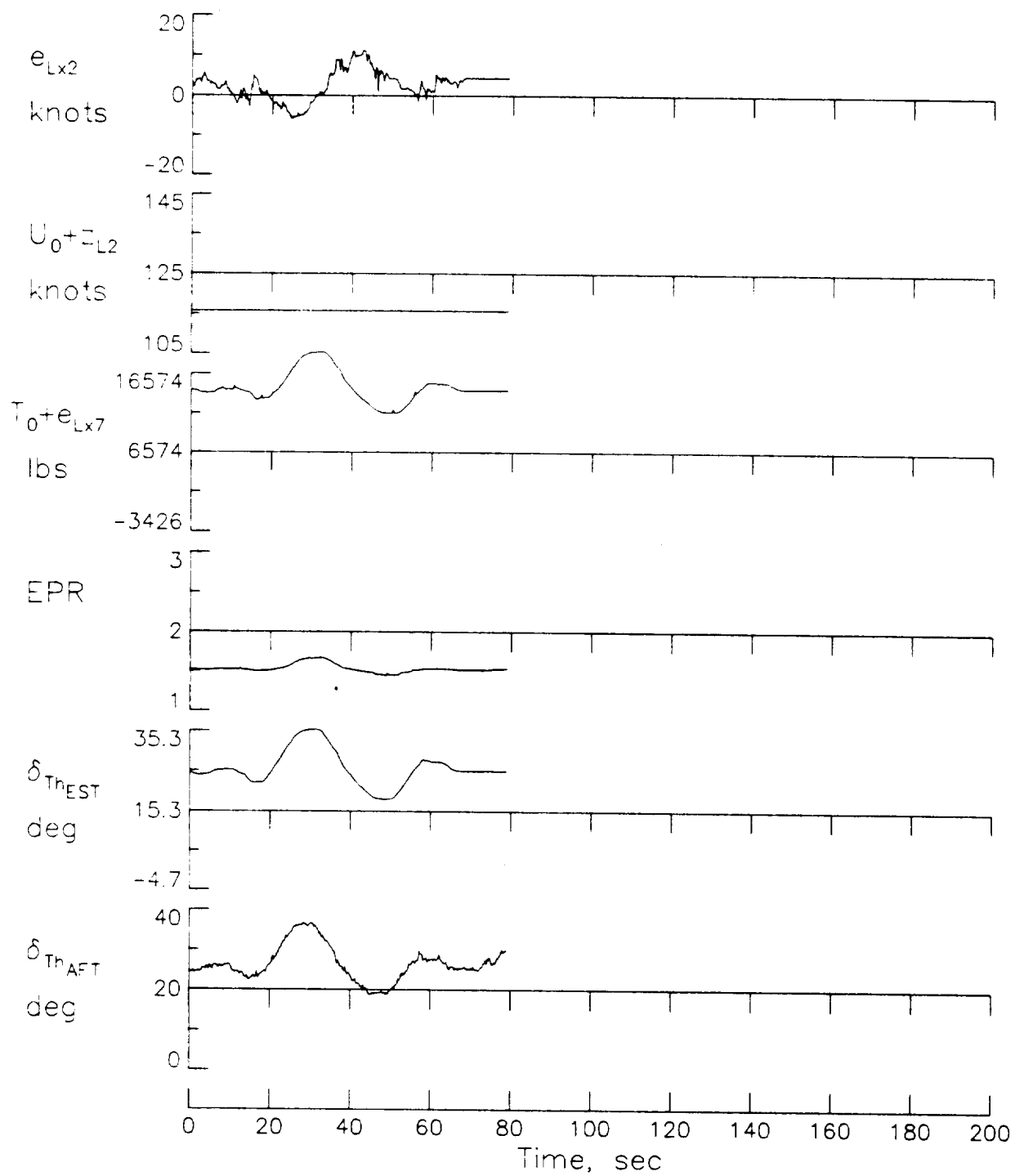


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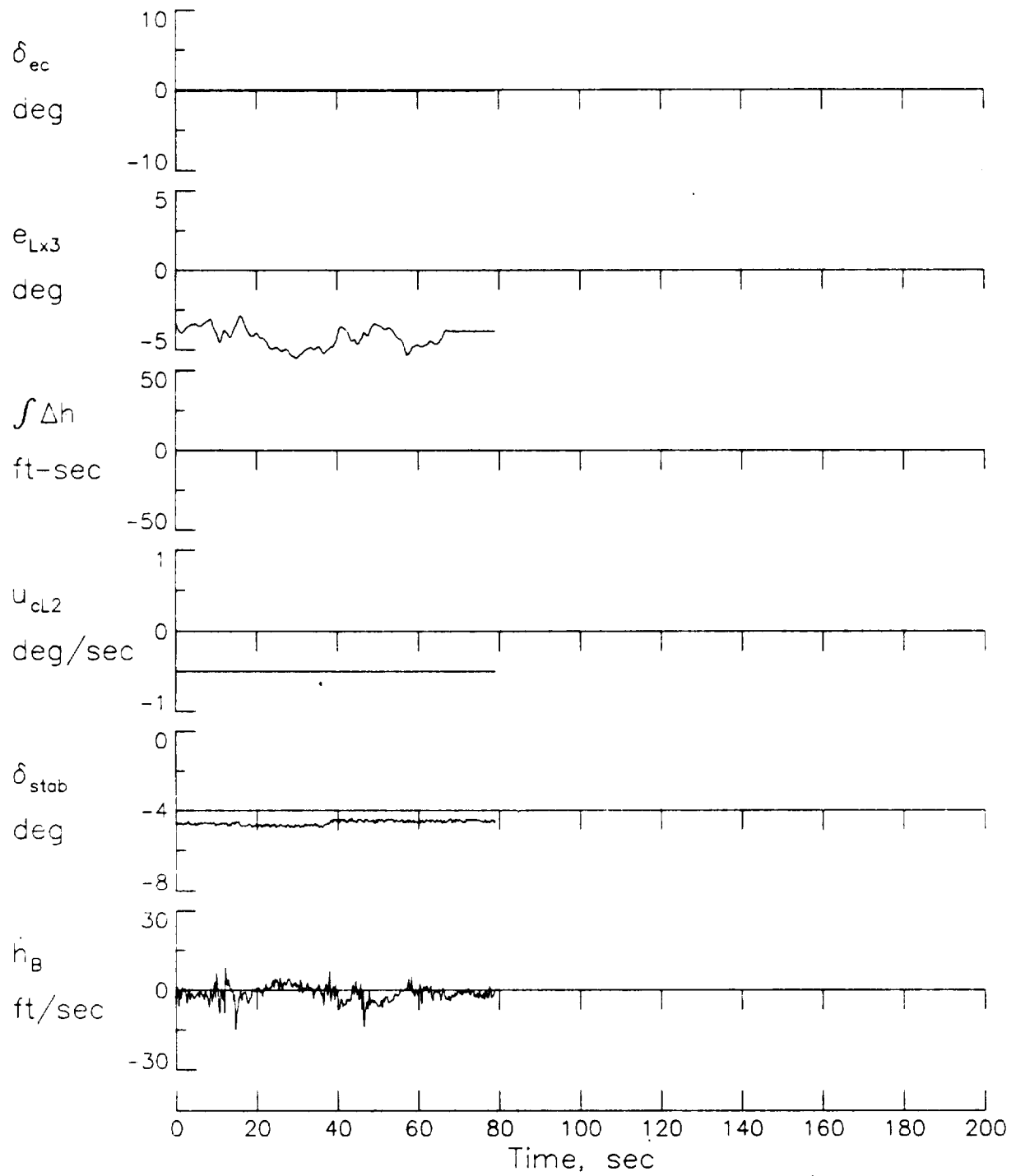


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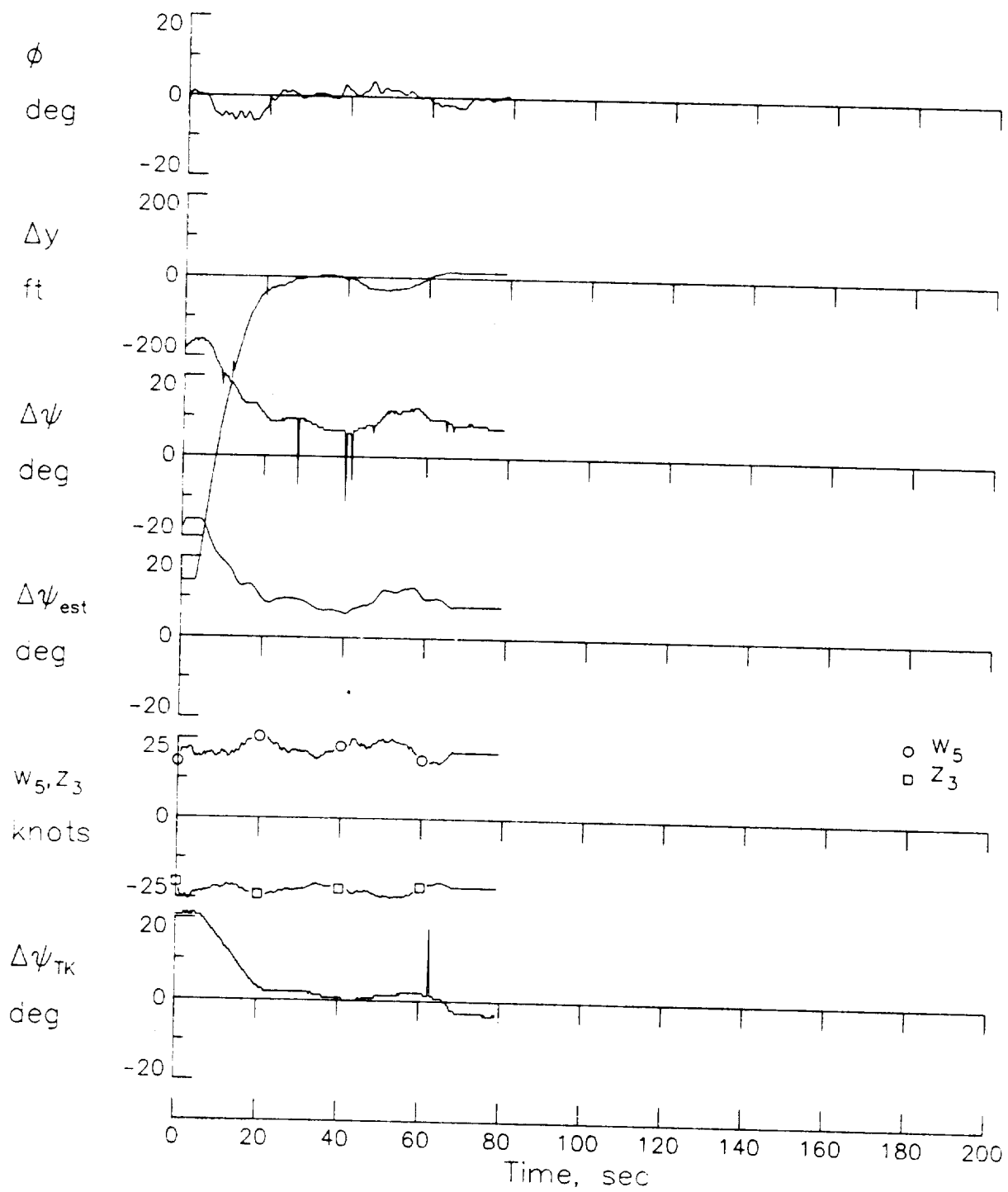


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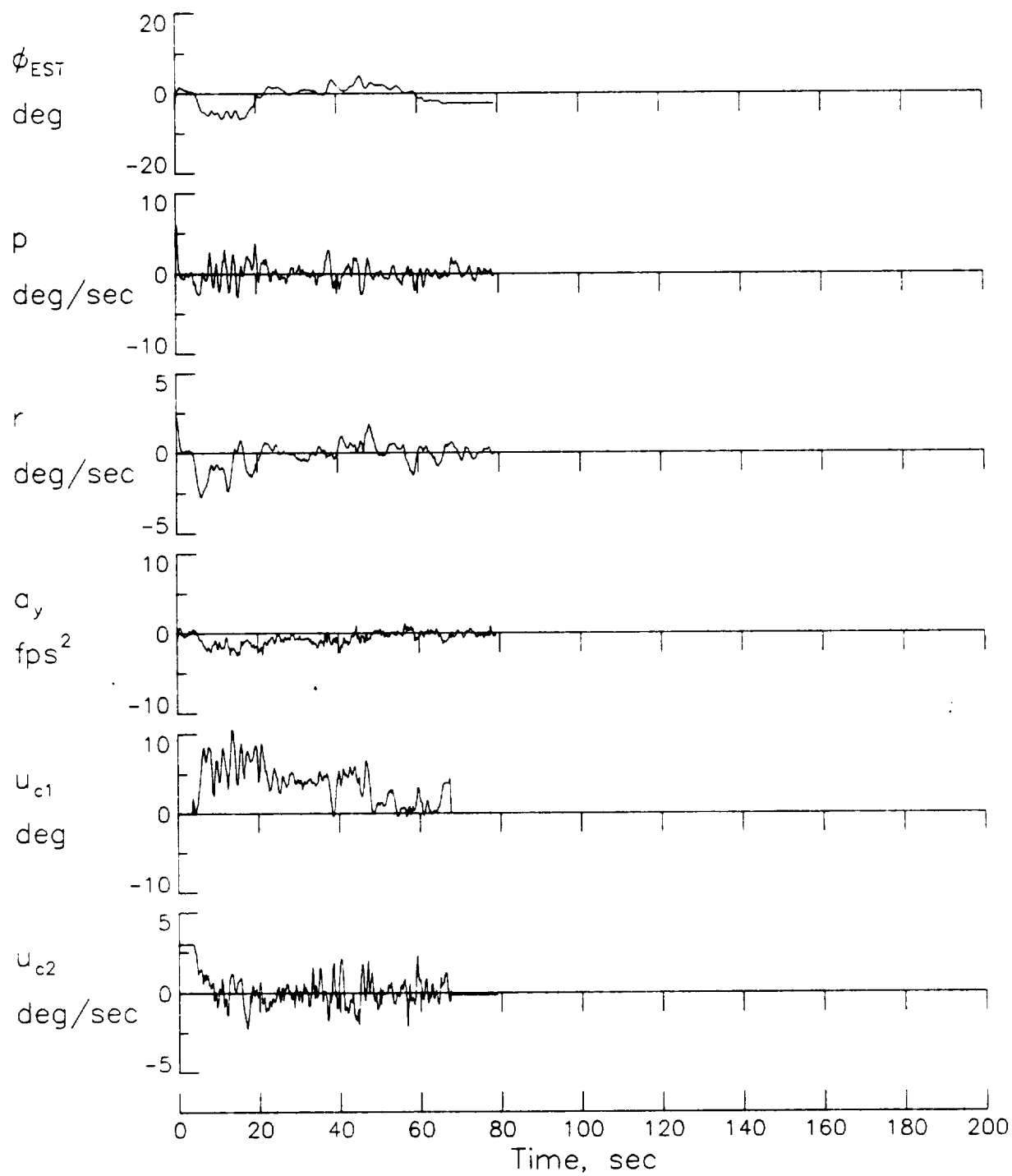


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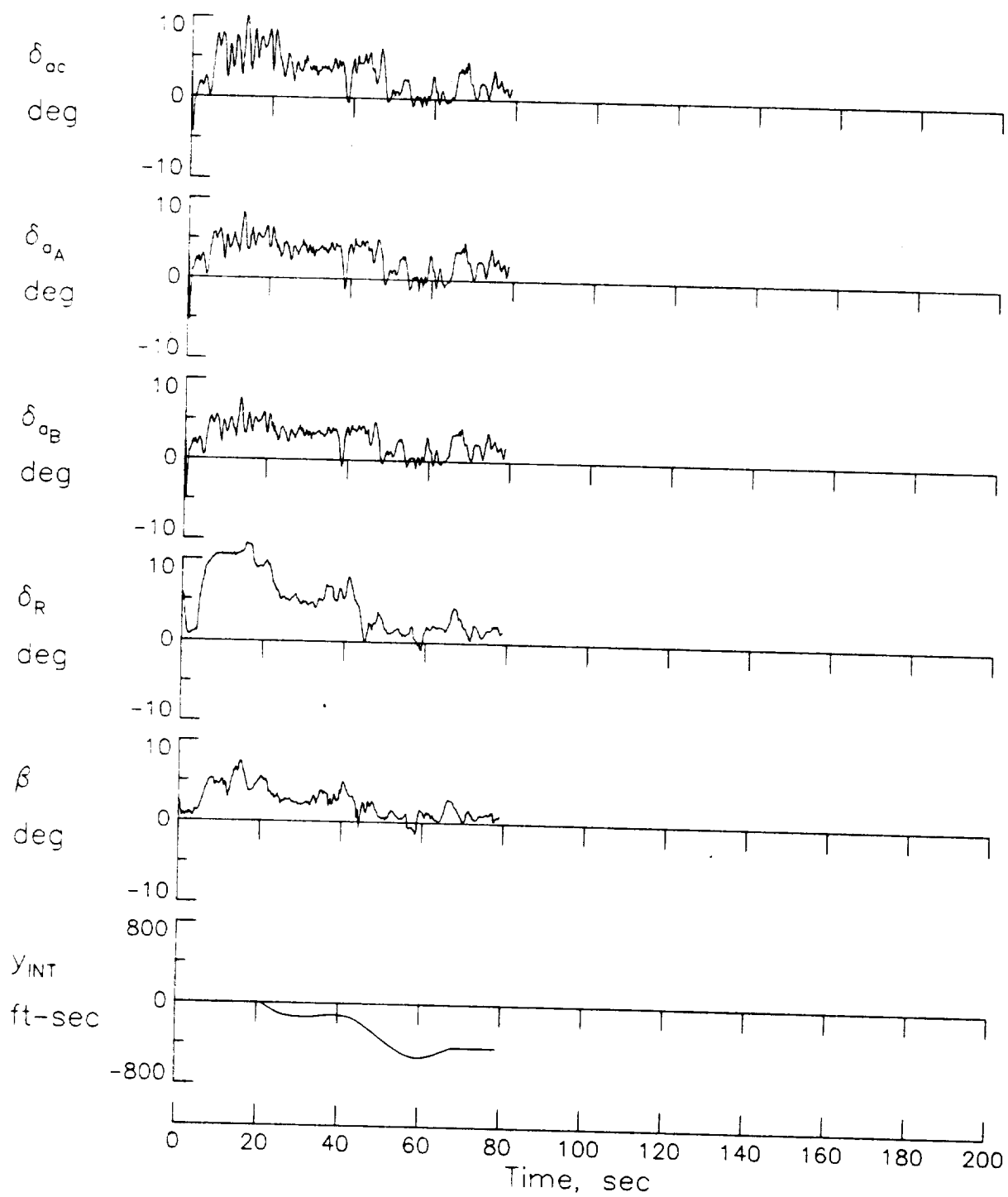


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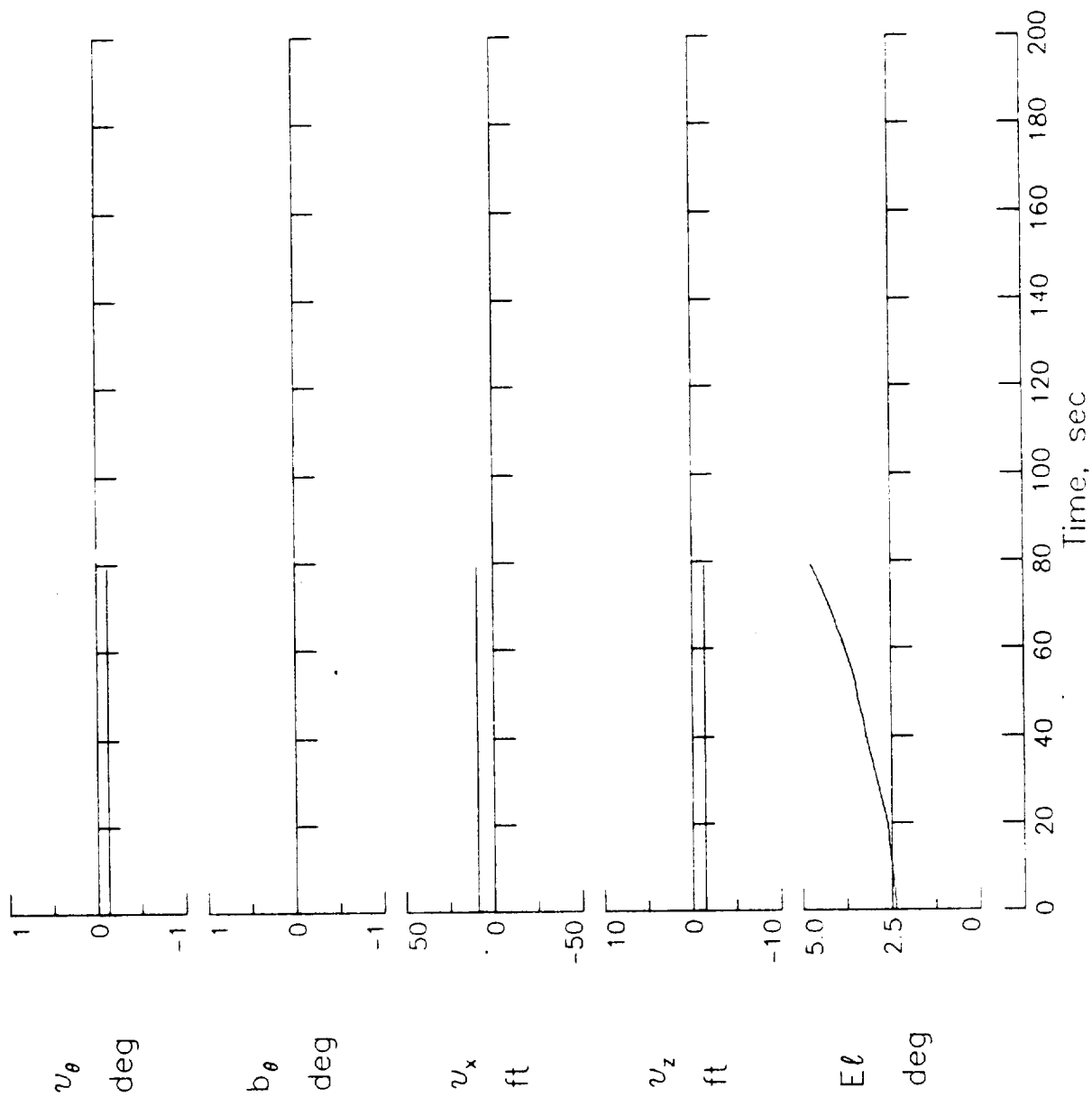


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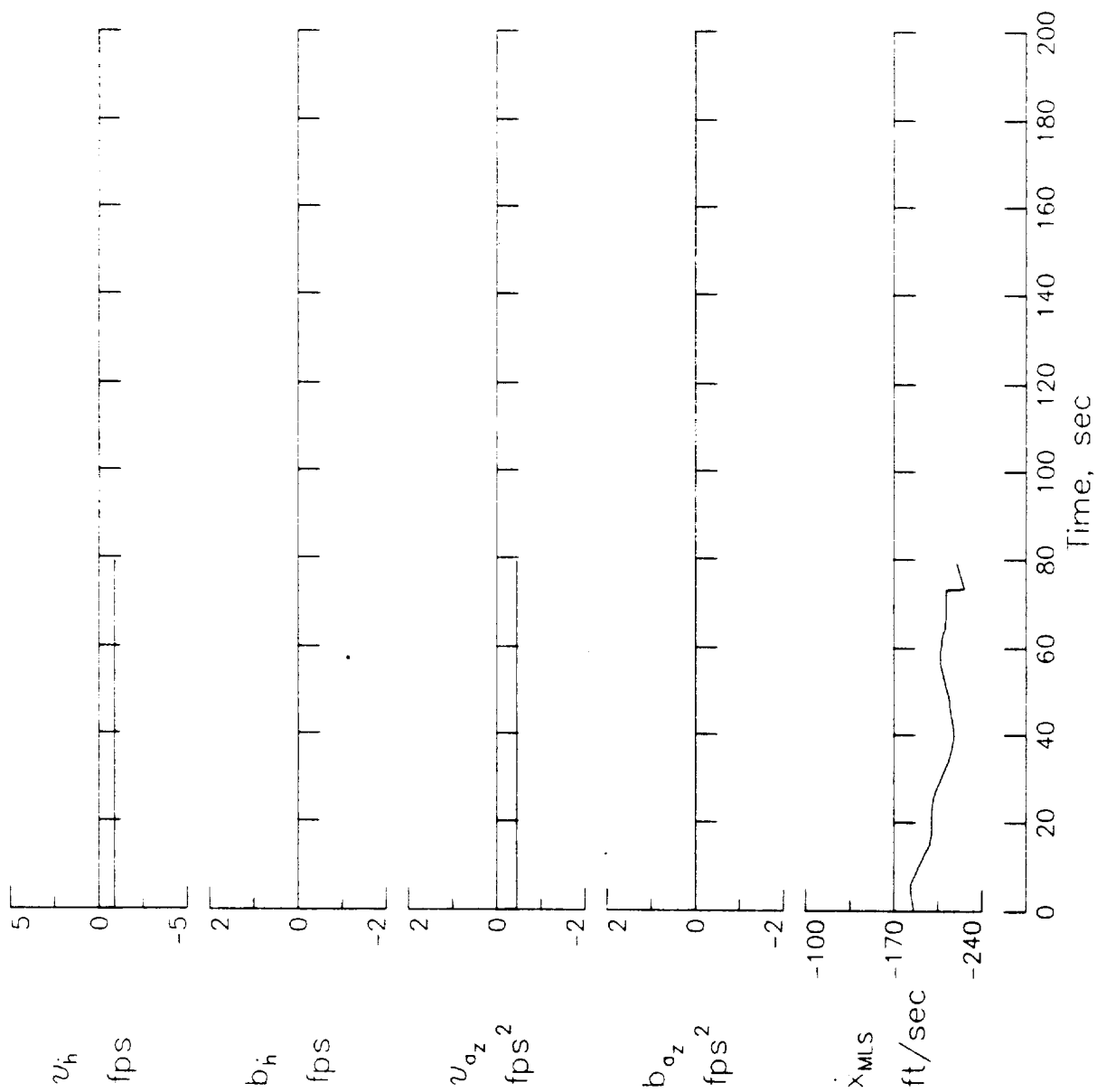


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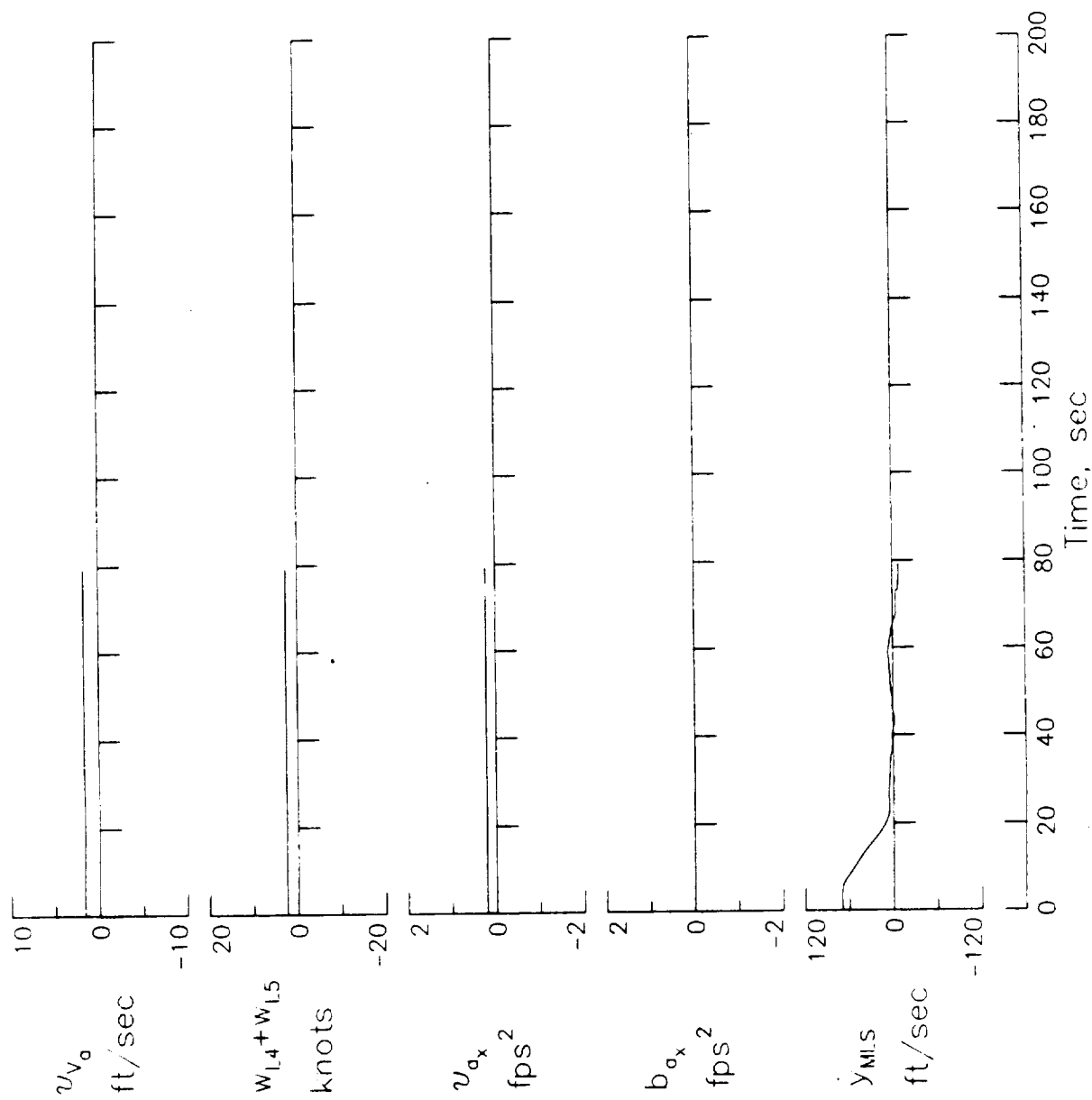


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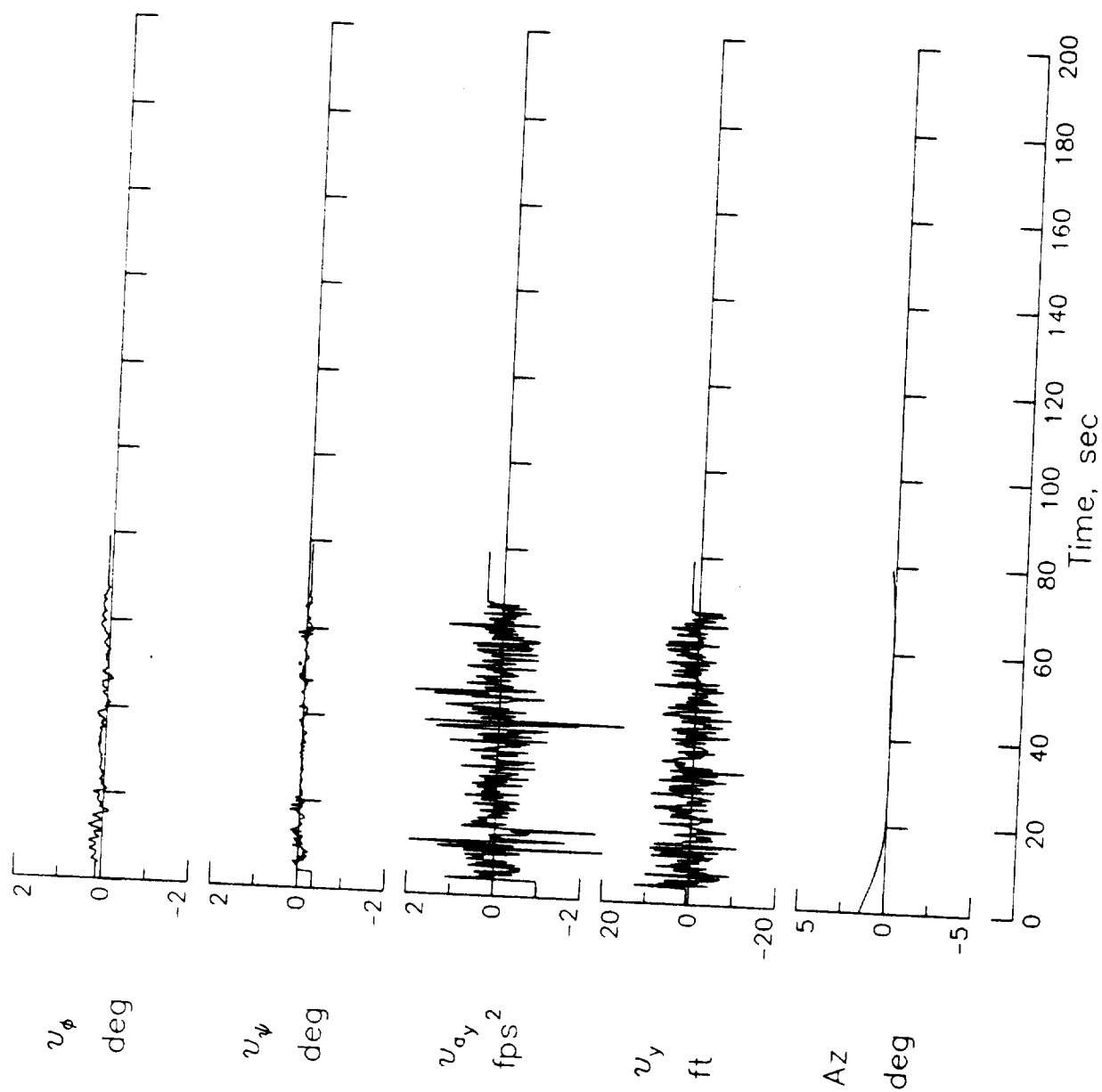


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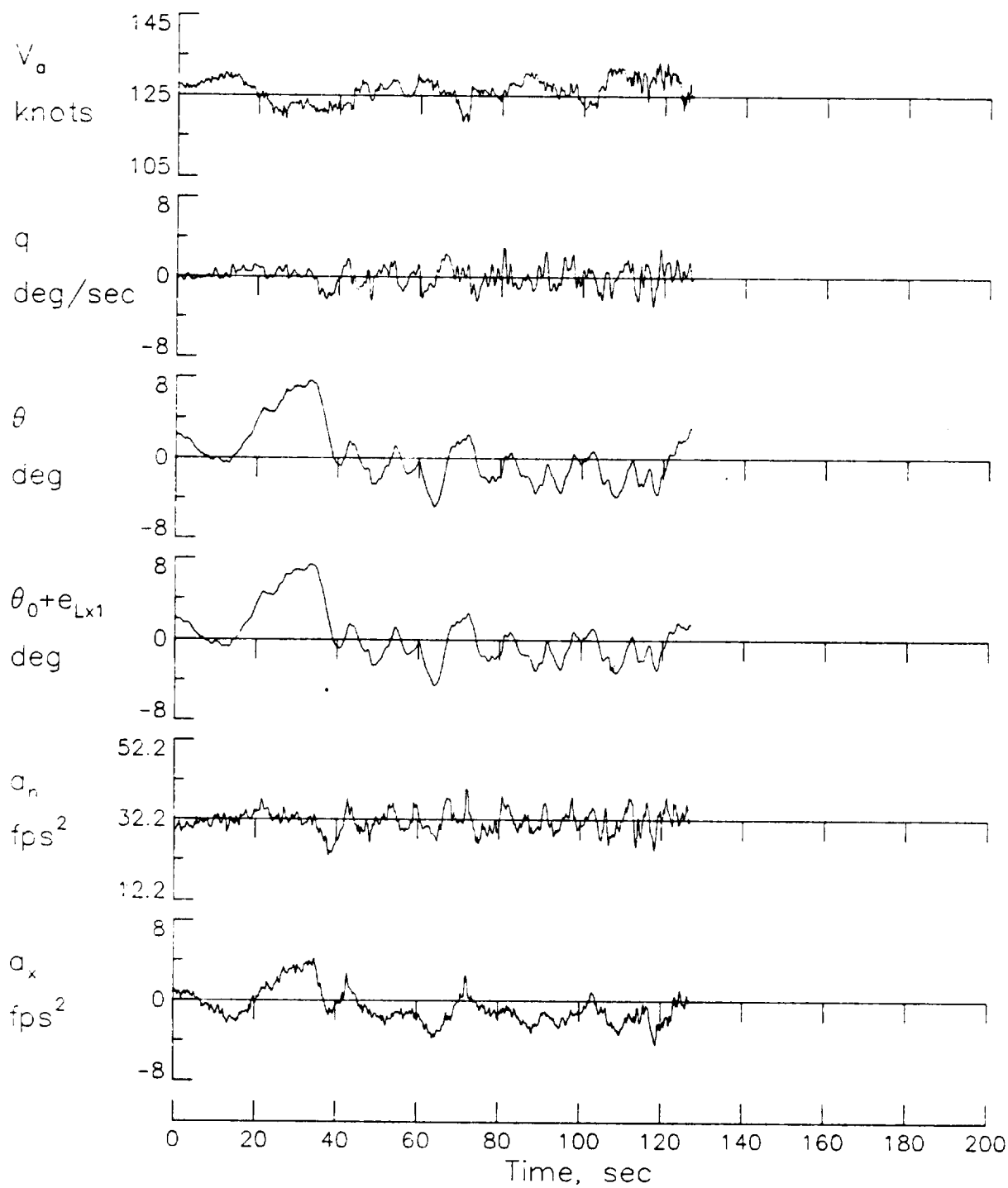


Figure 18. Flight Data for DIALS Flight Test
R357, Run 8R1

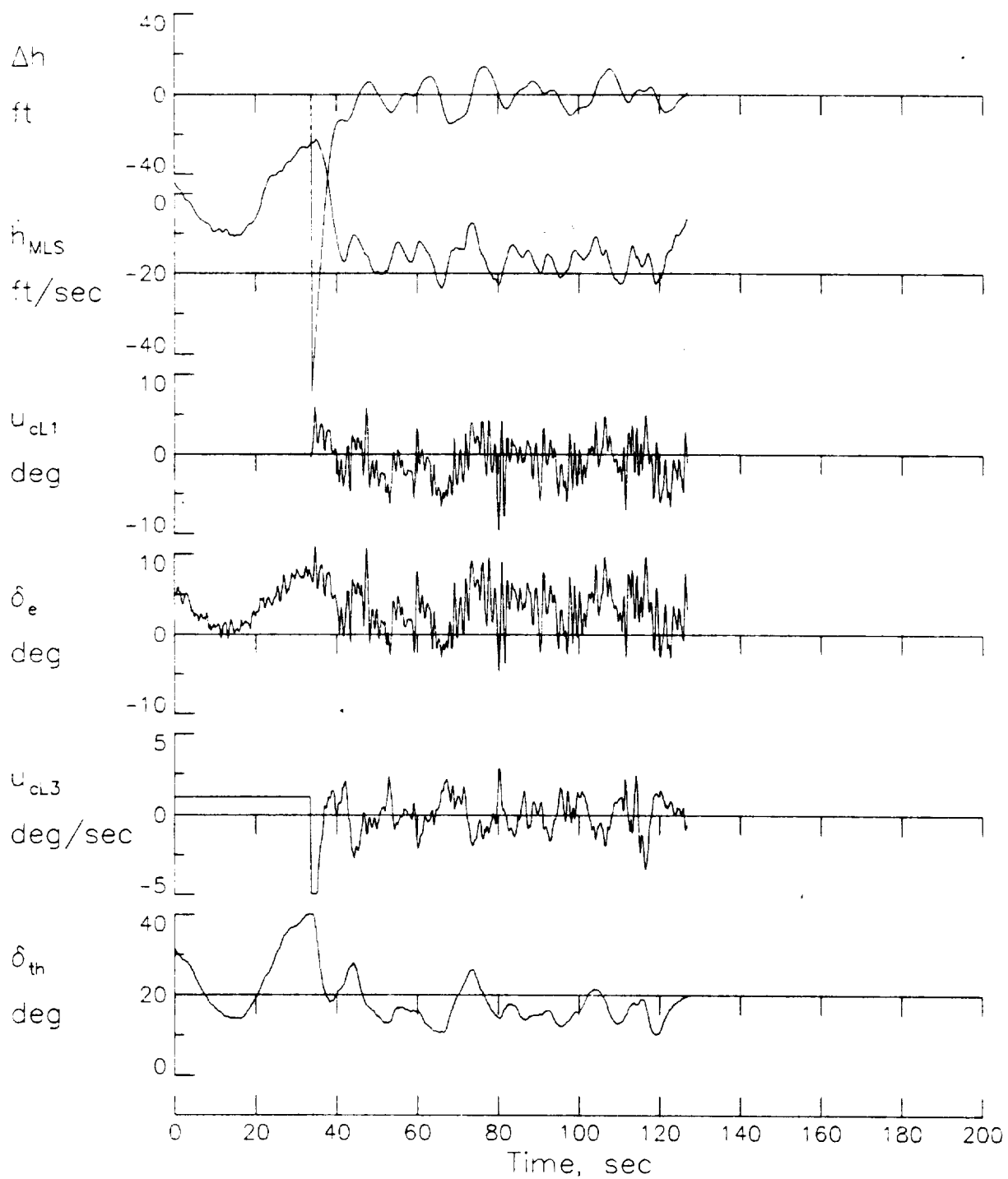


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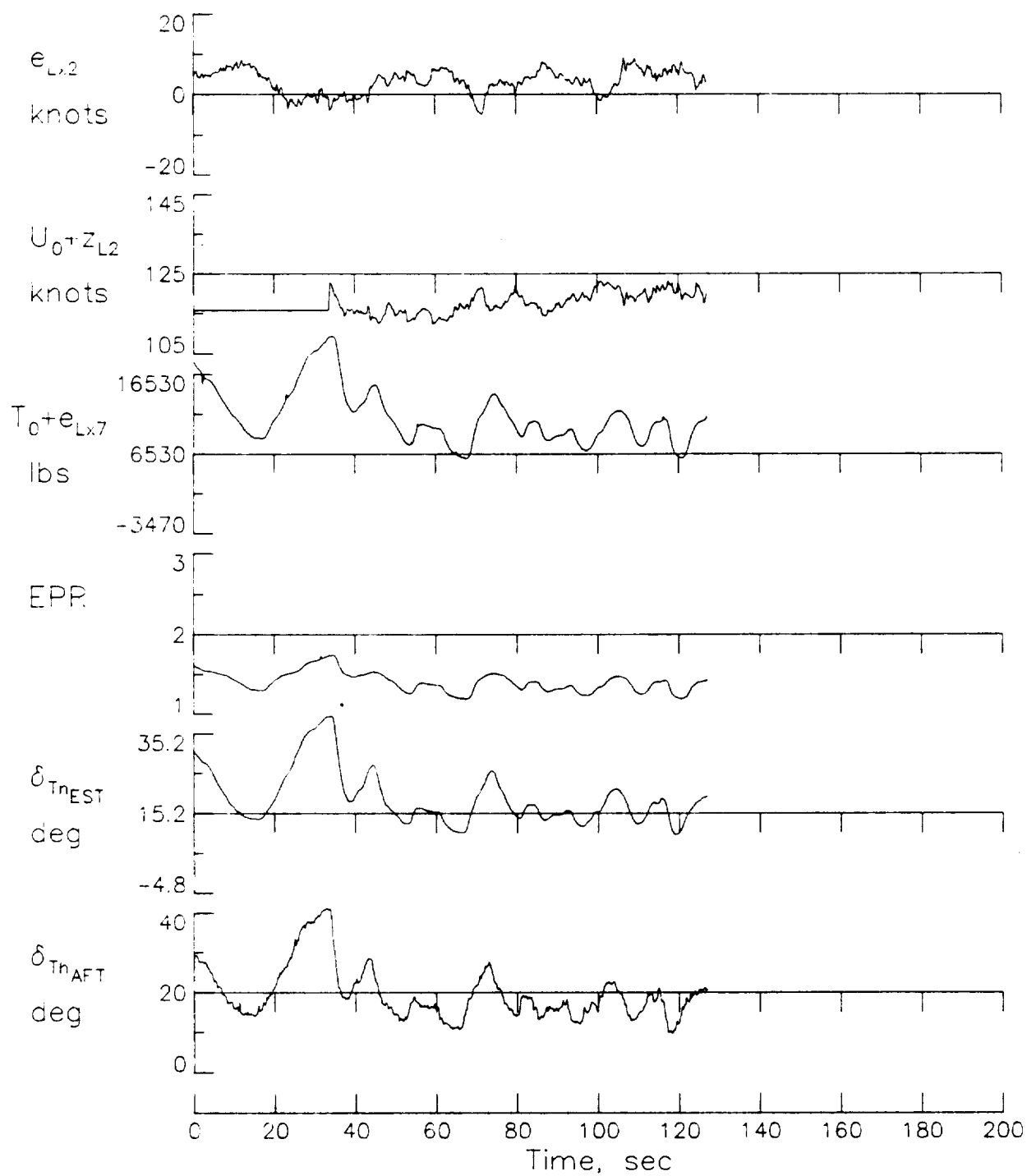


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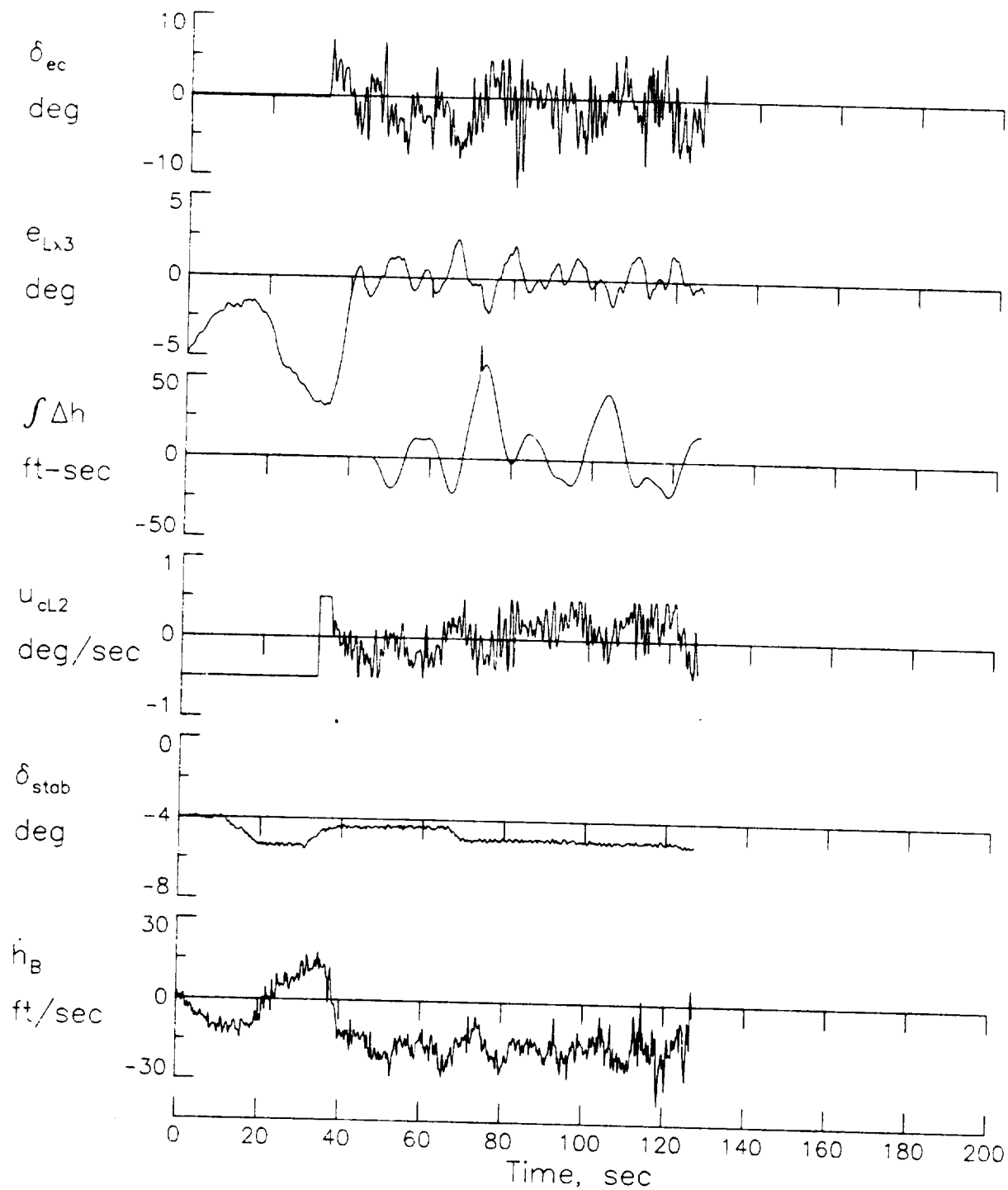


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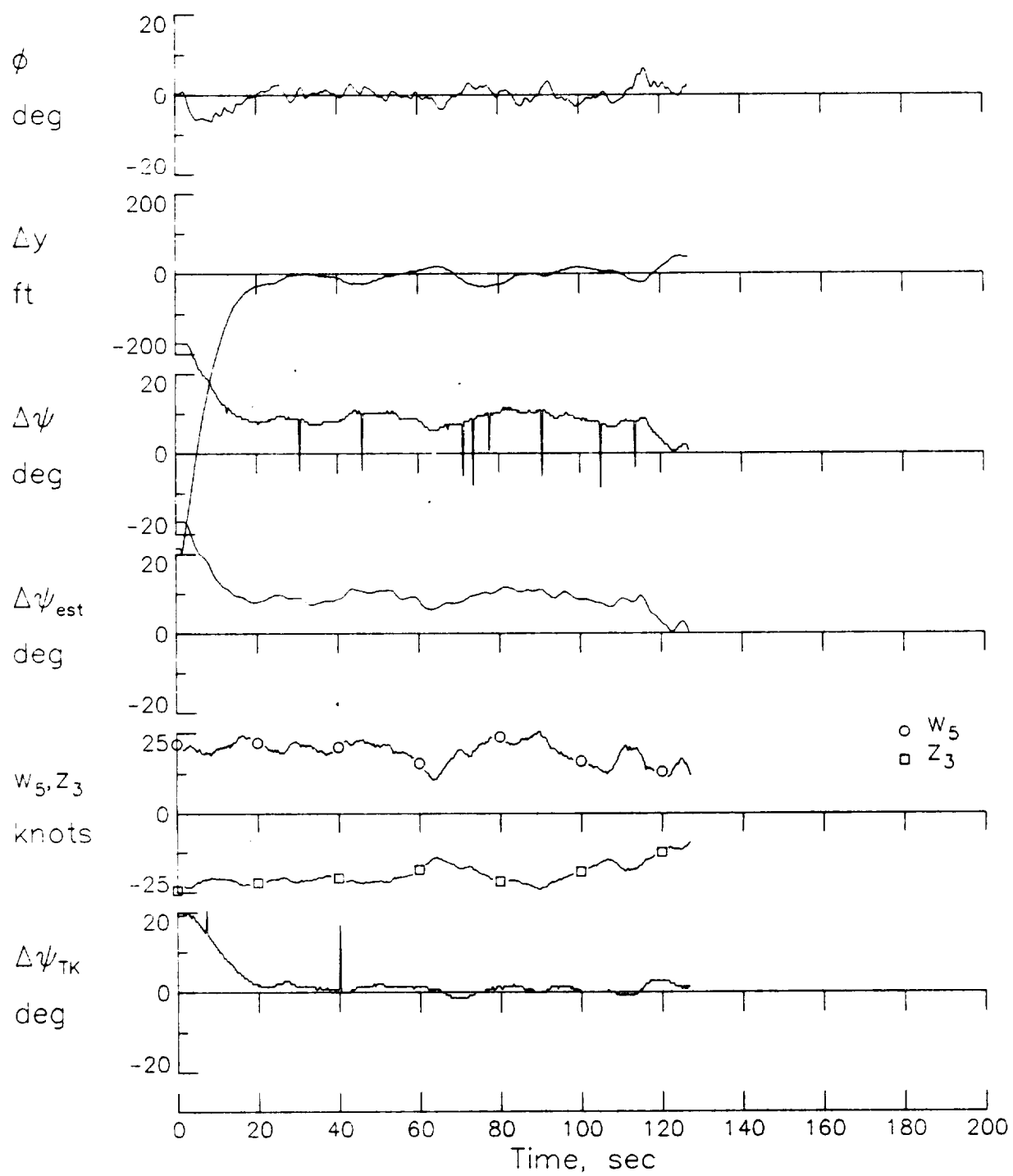


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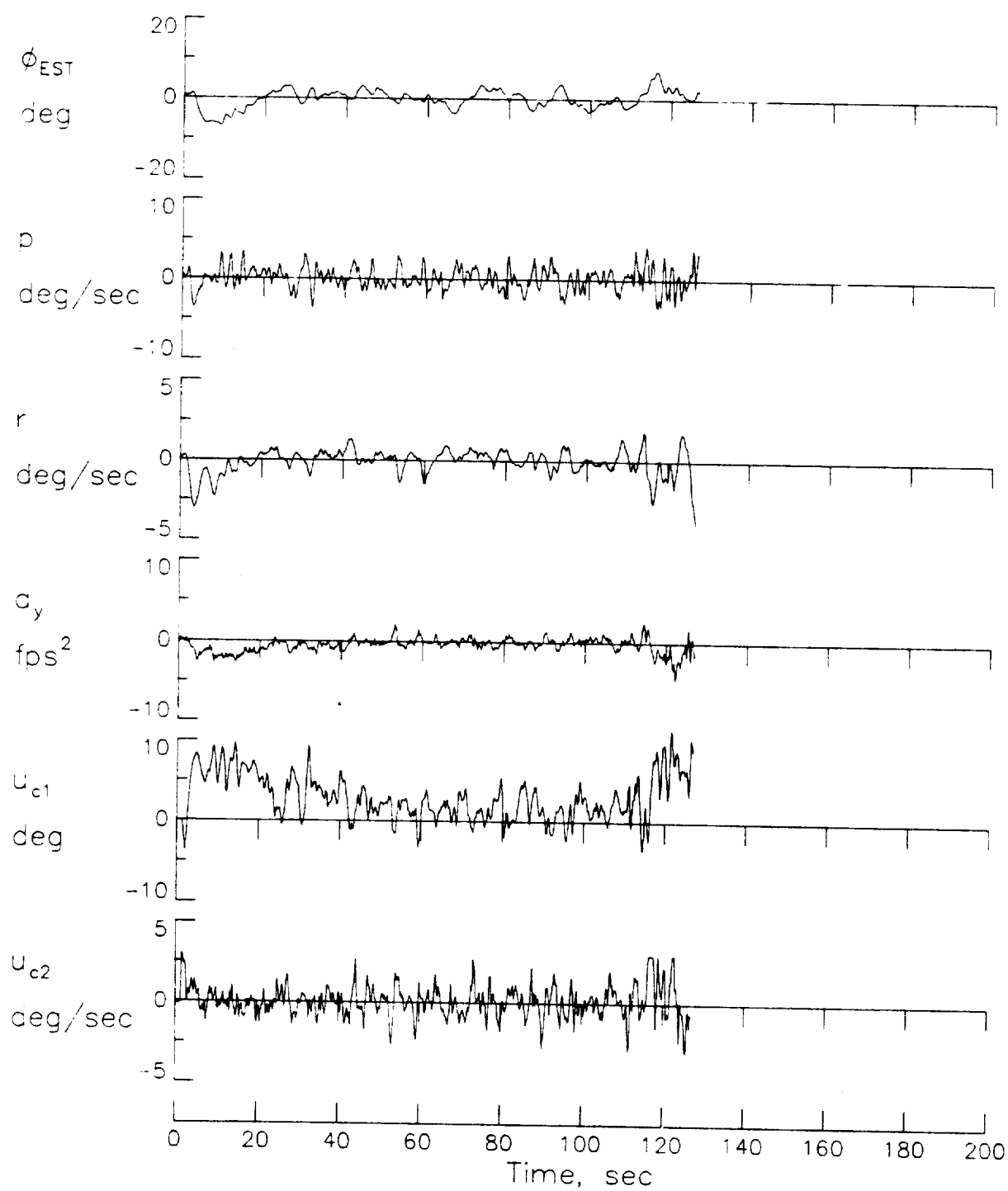


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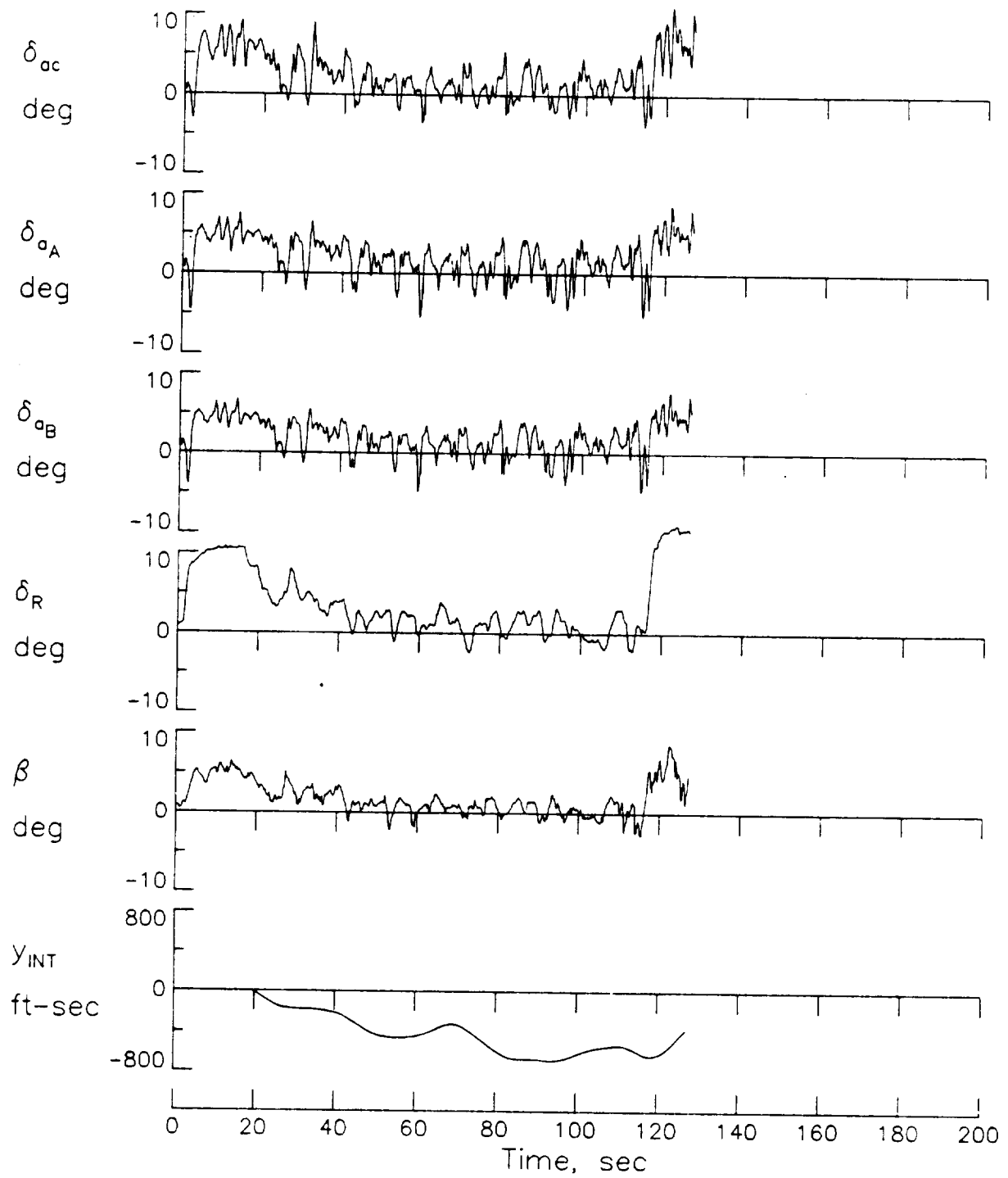


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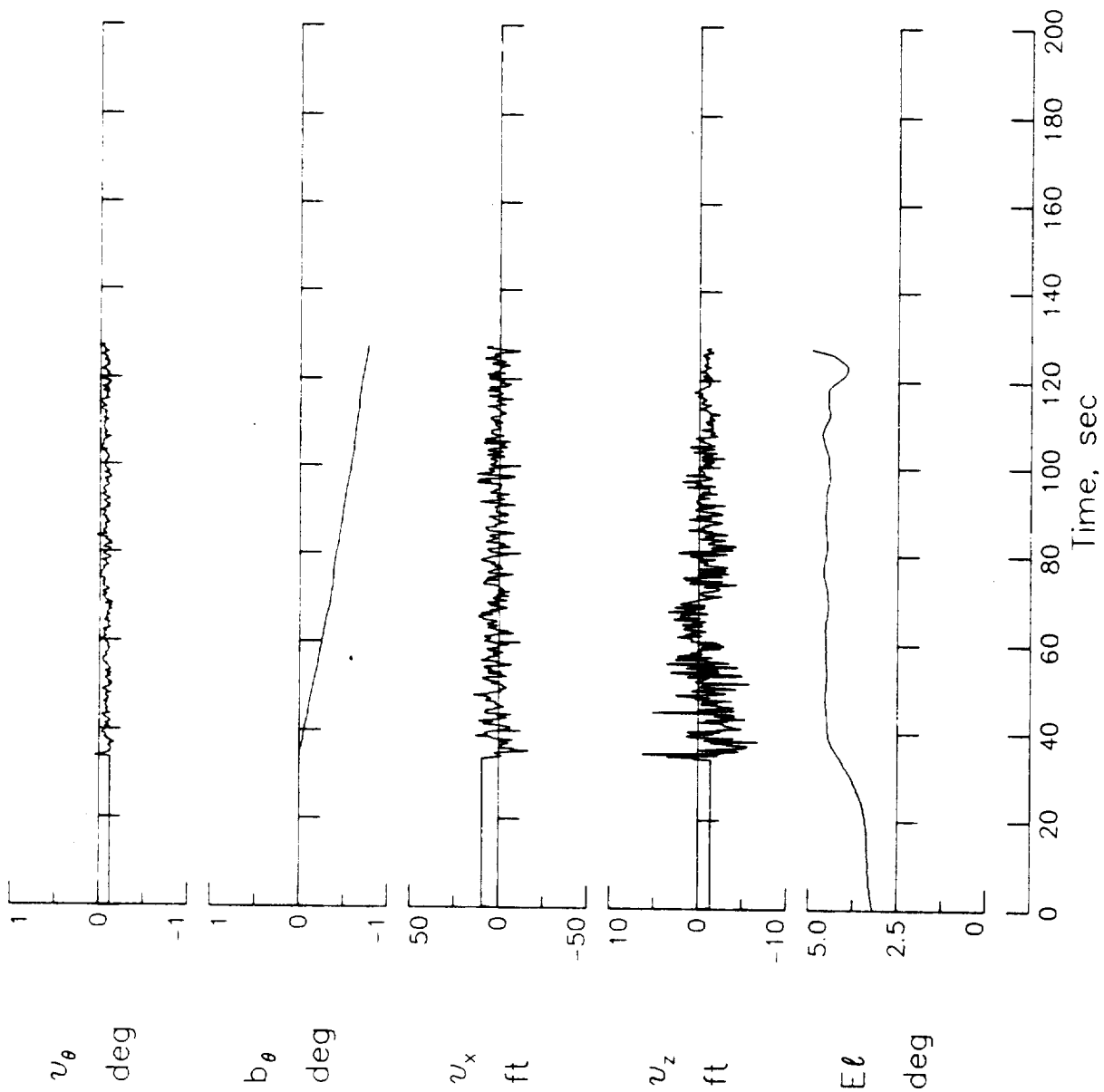


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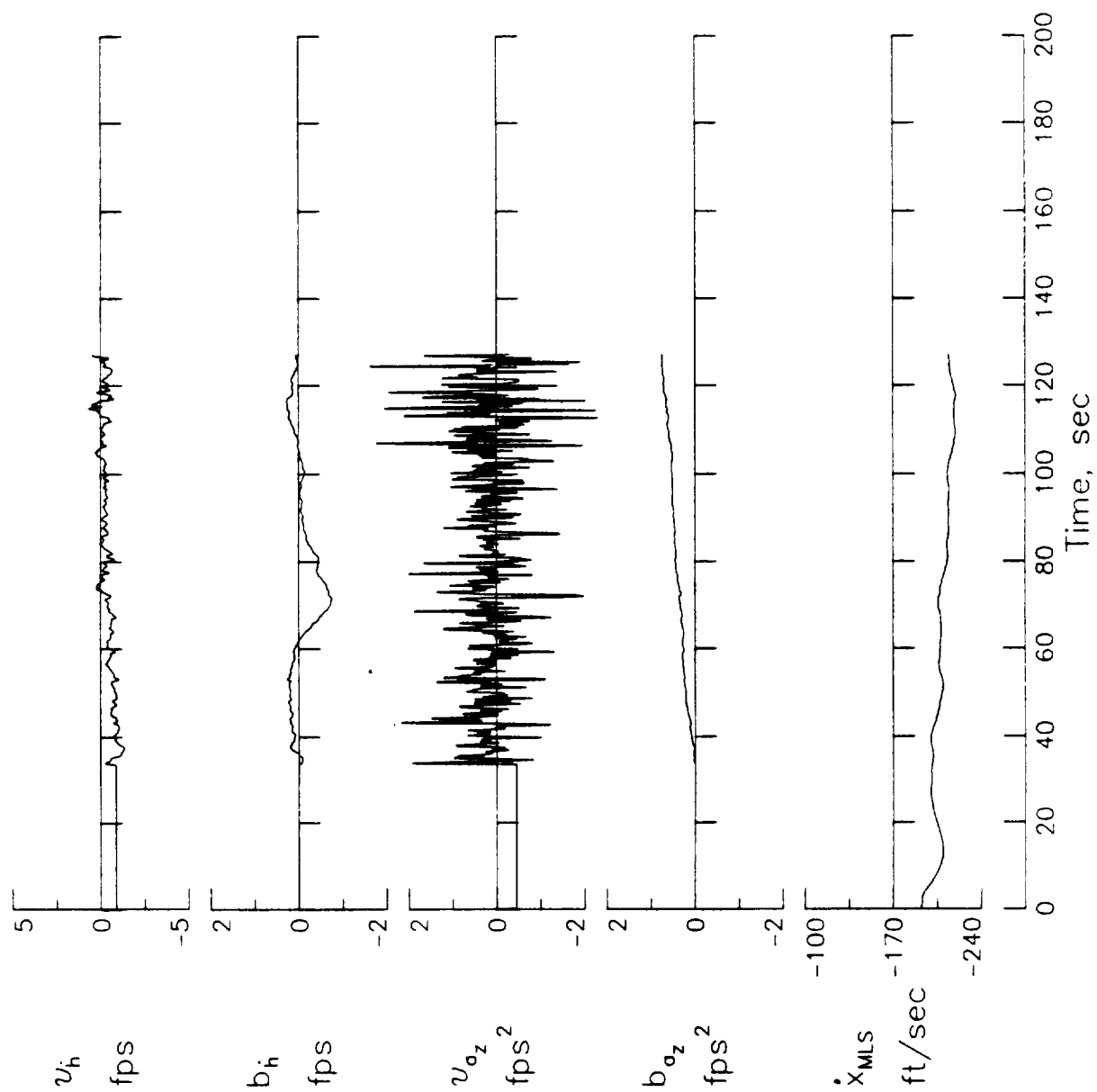


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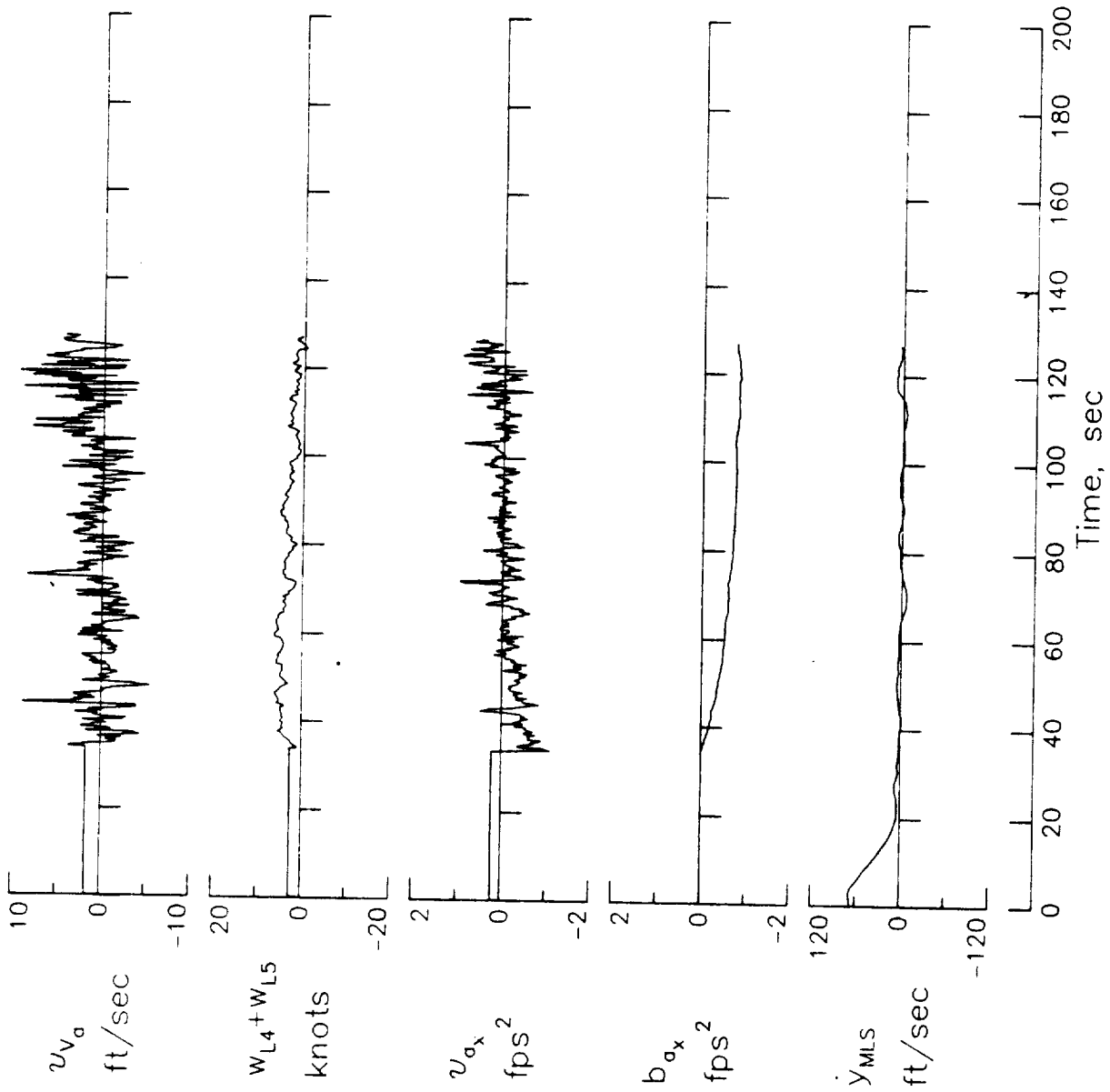


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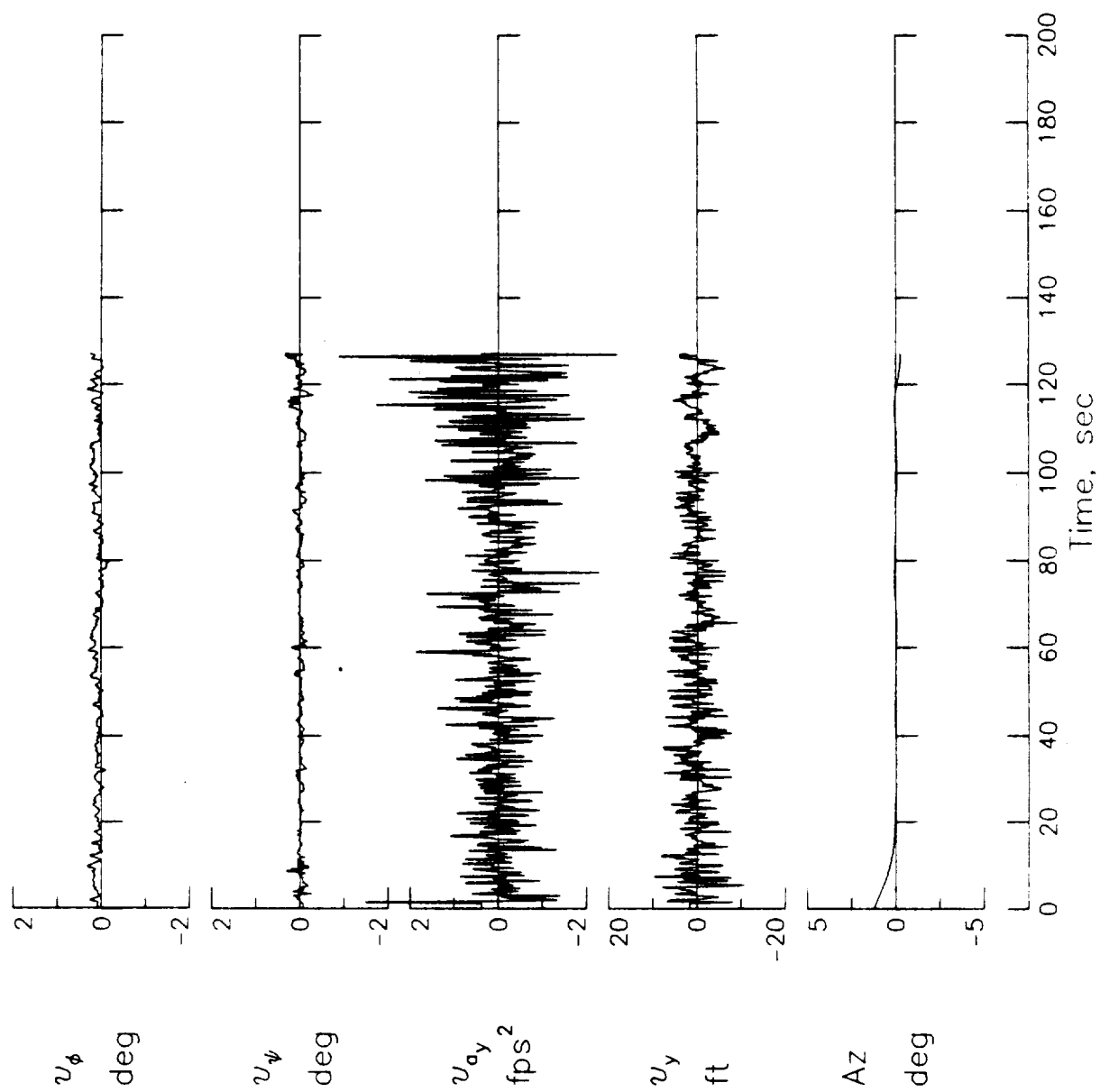


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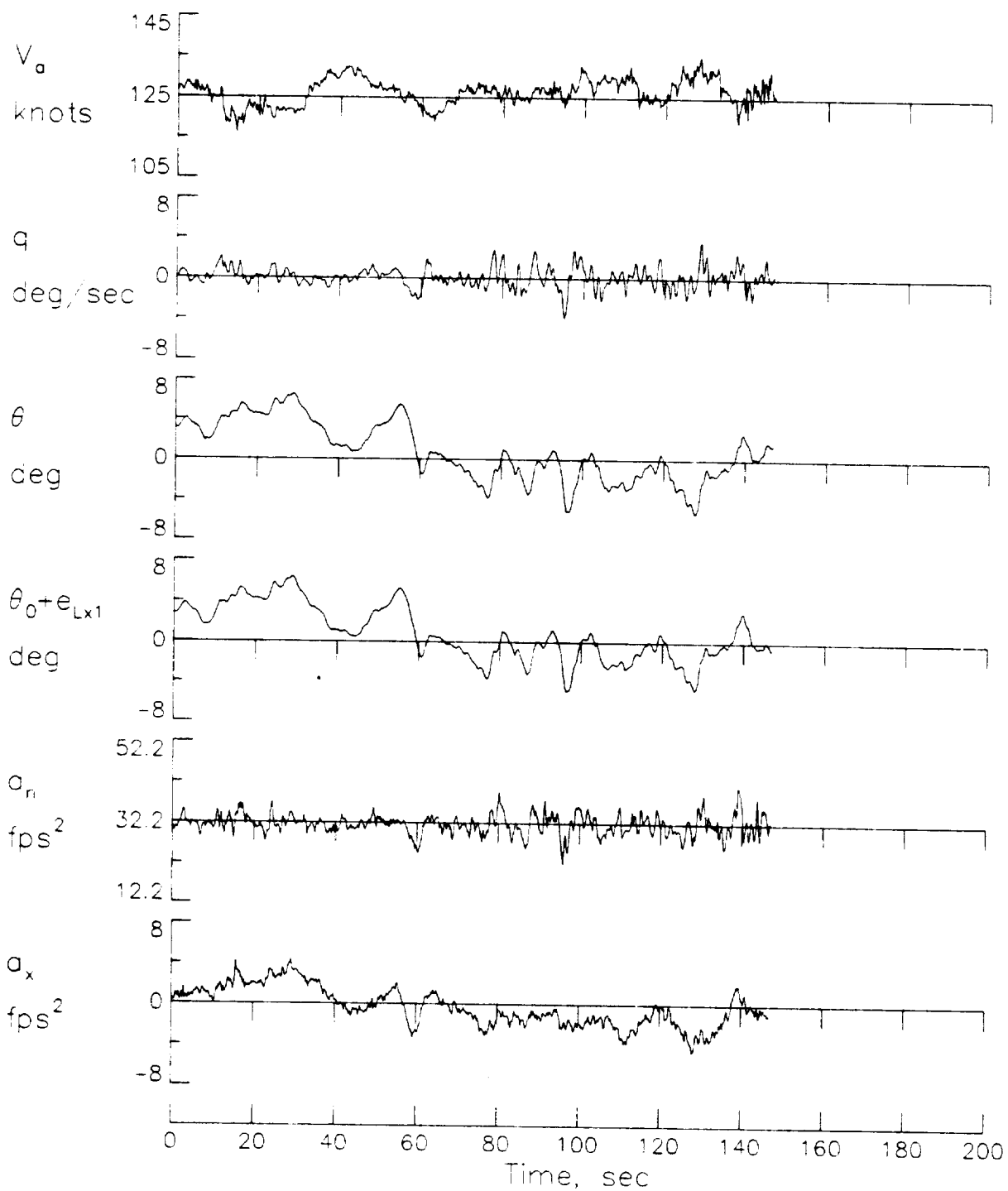


Figure 19. Flight Data for DIALS Flight Test R357, Run 9

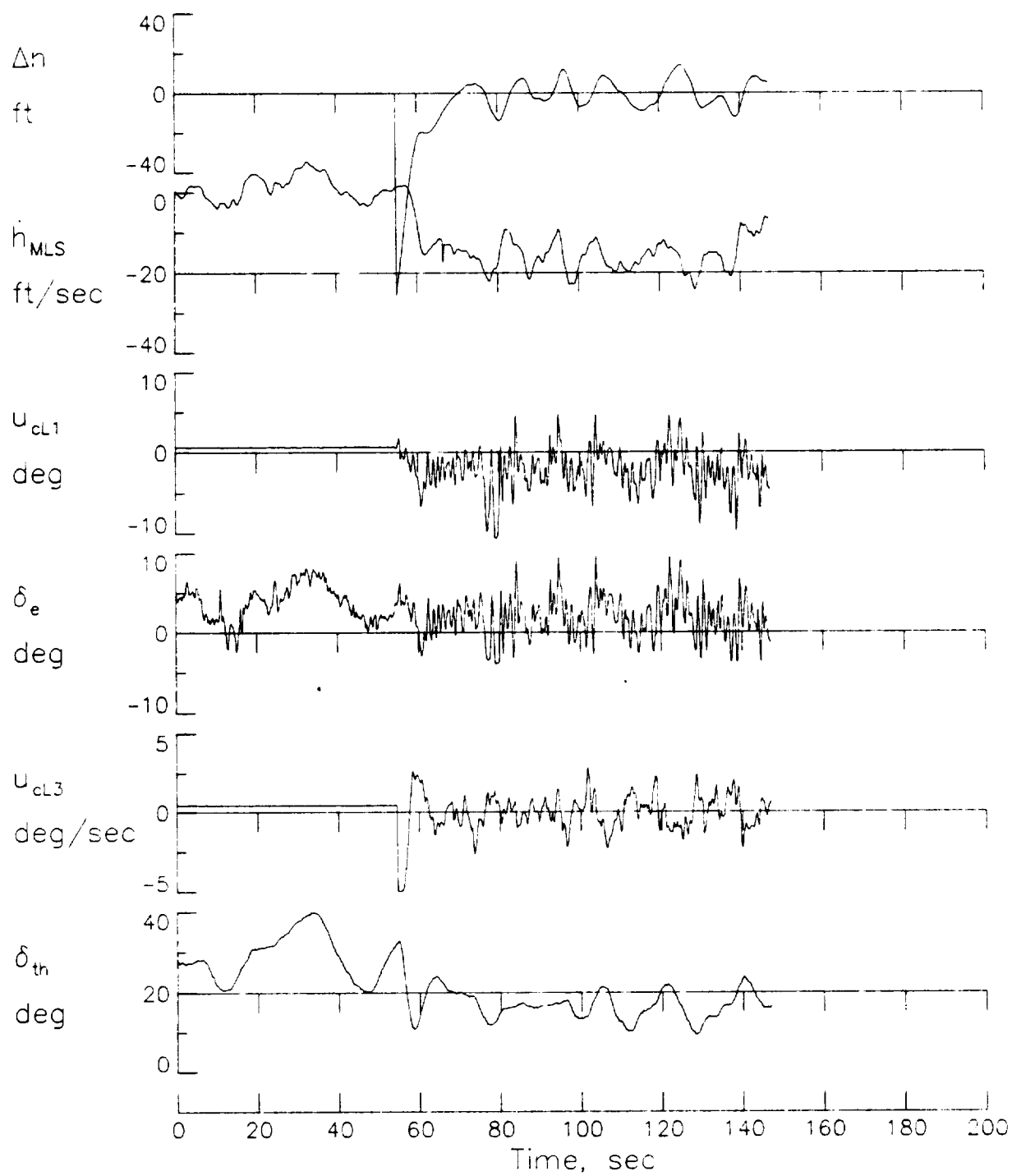


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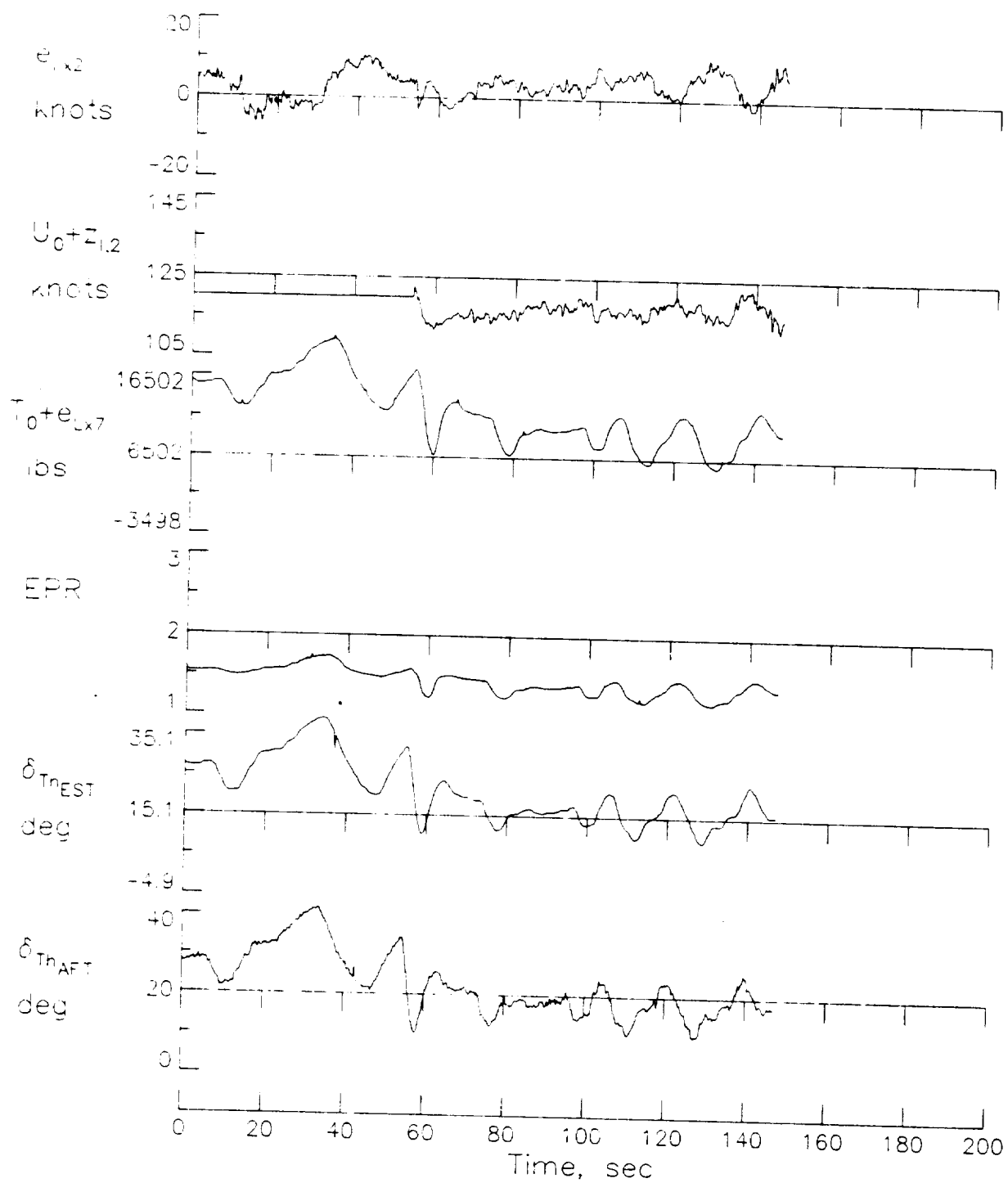


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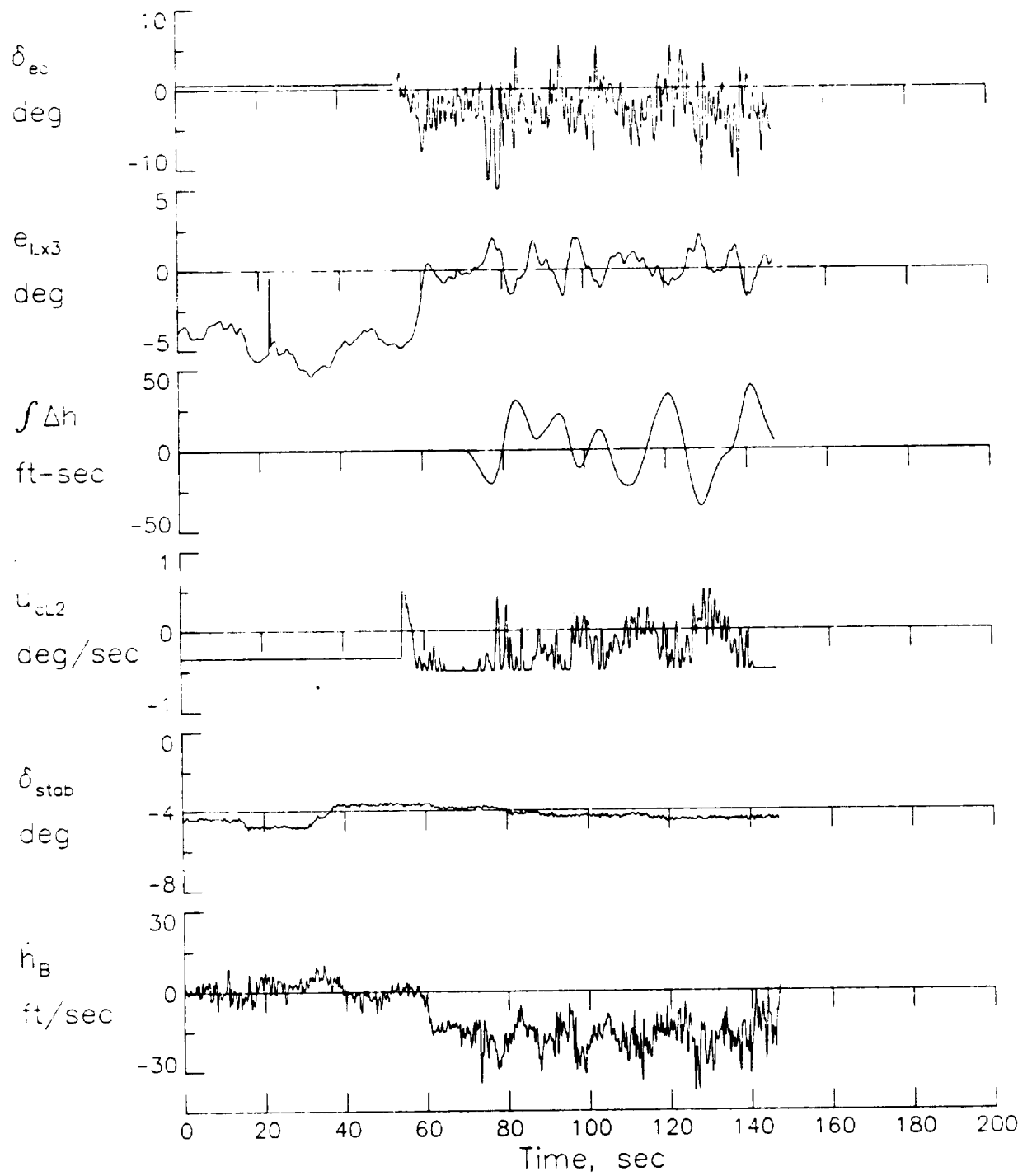


Figure 19. Continued

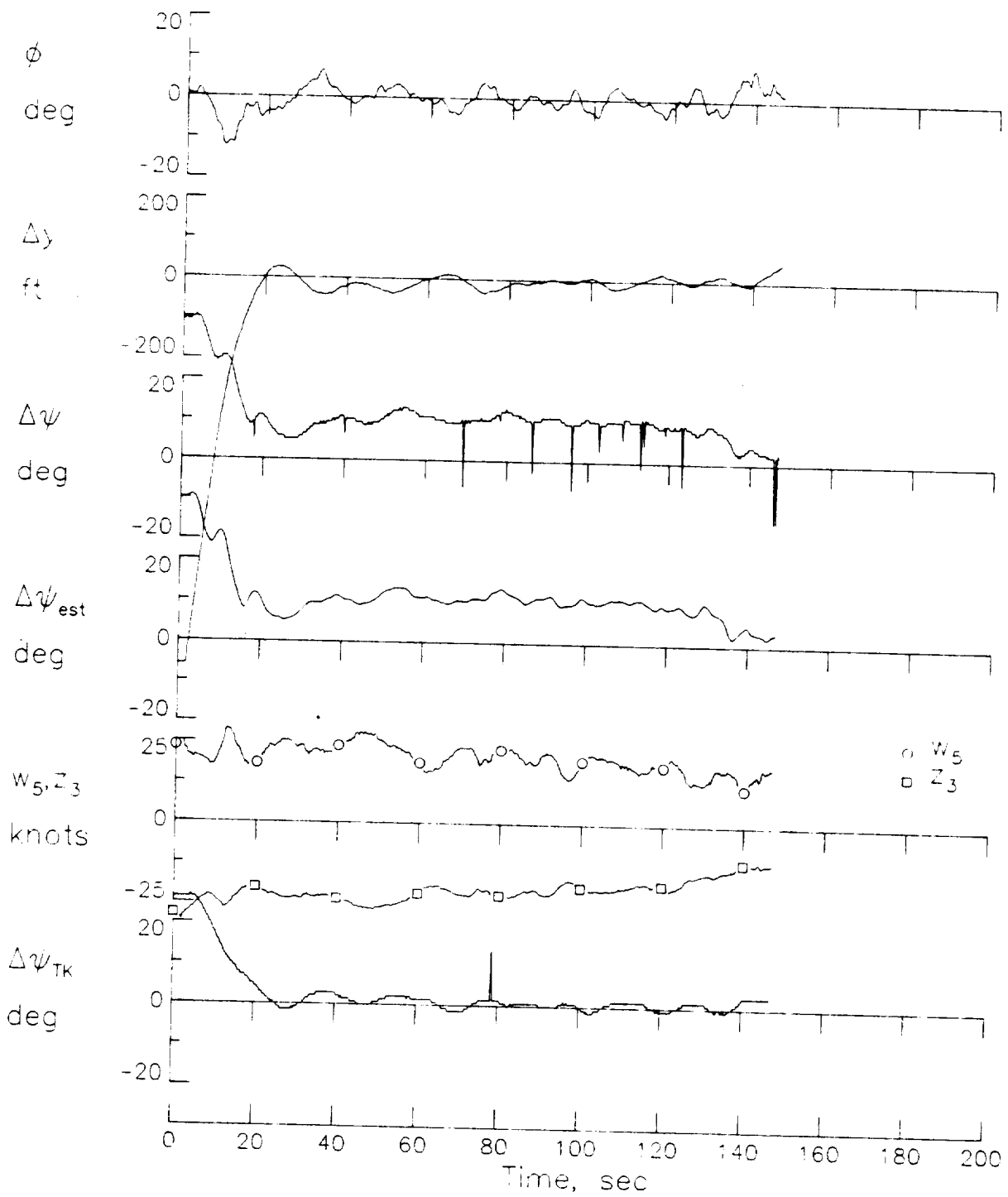


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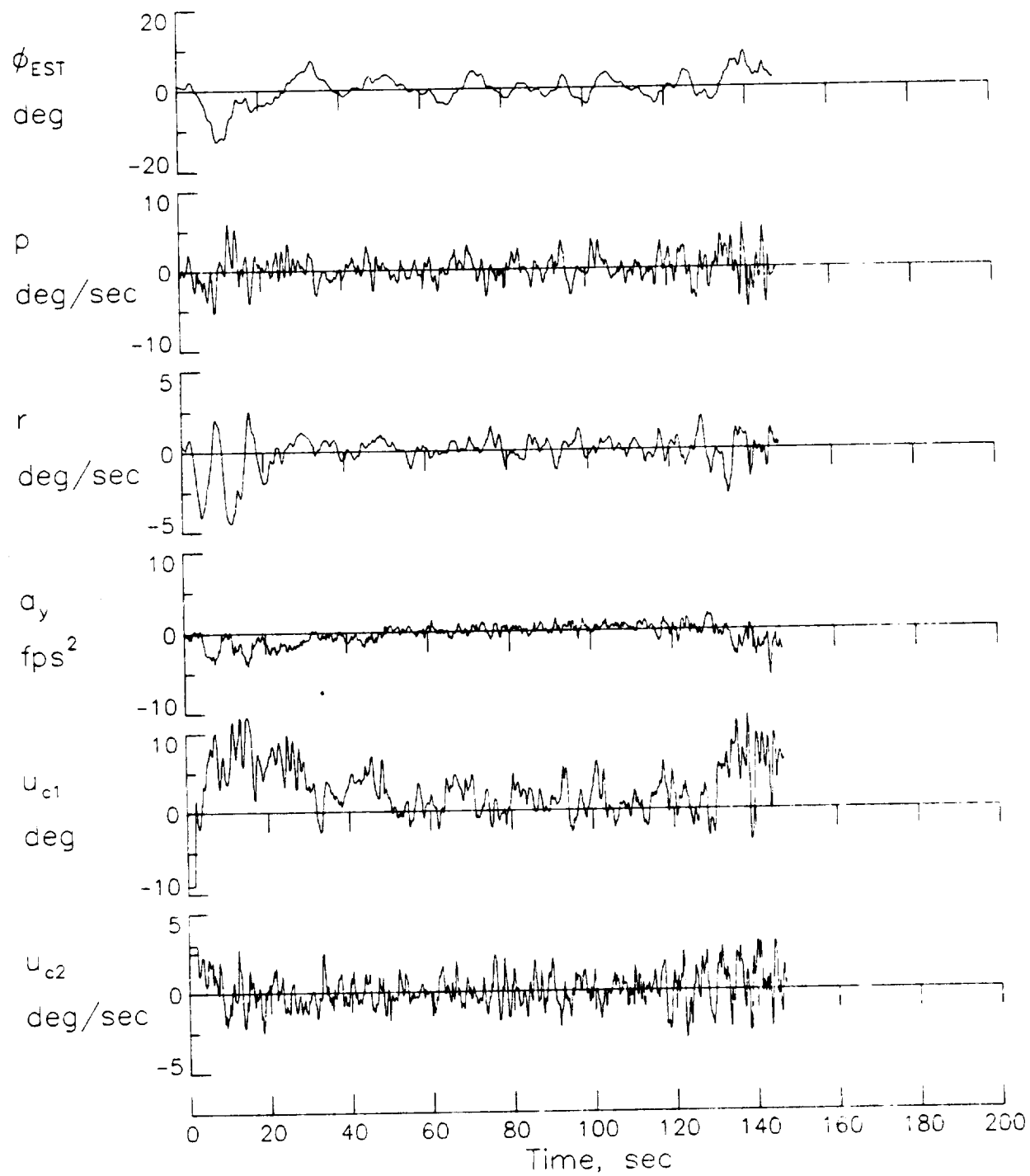


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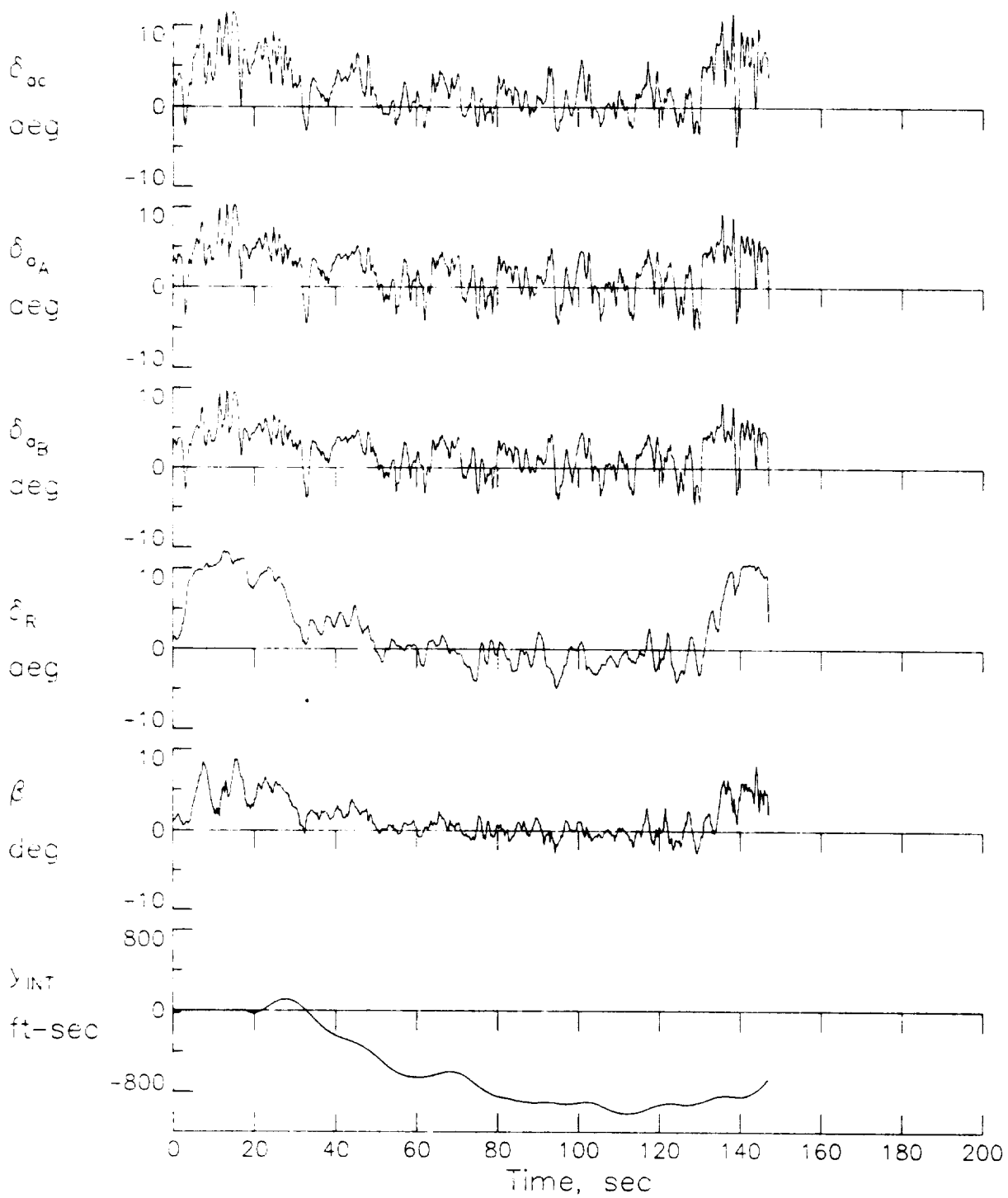


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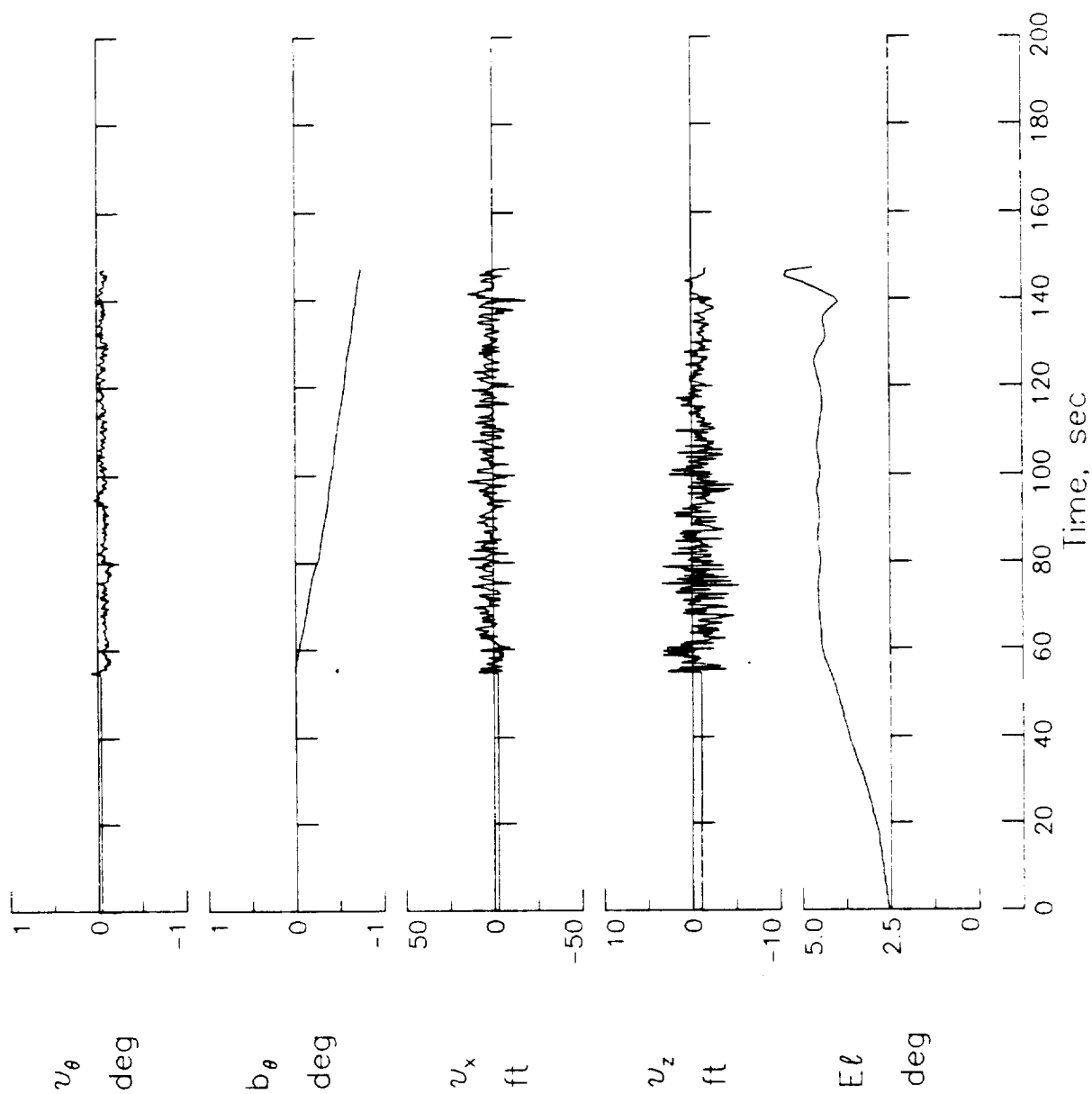


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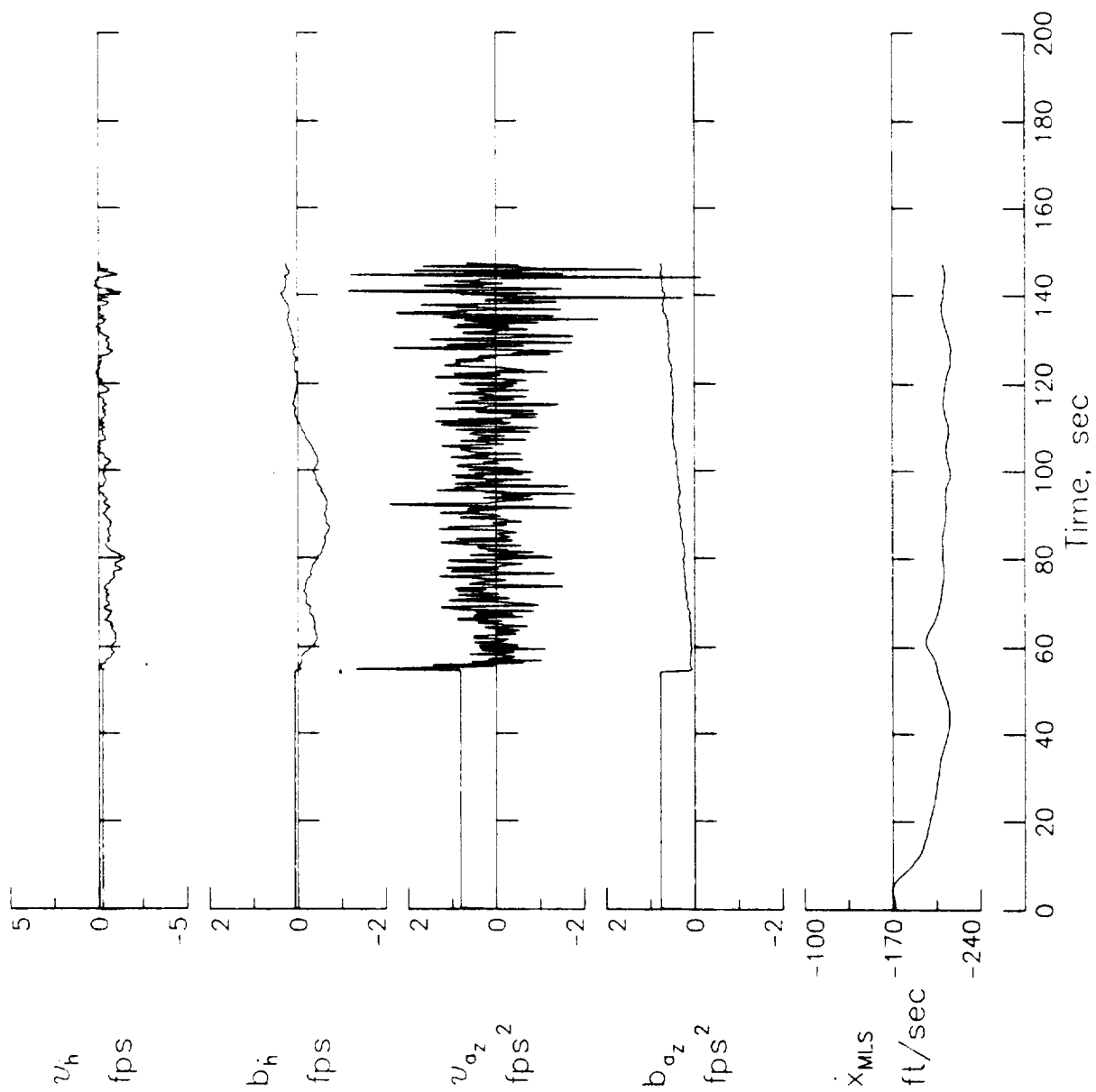


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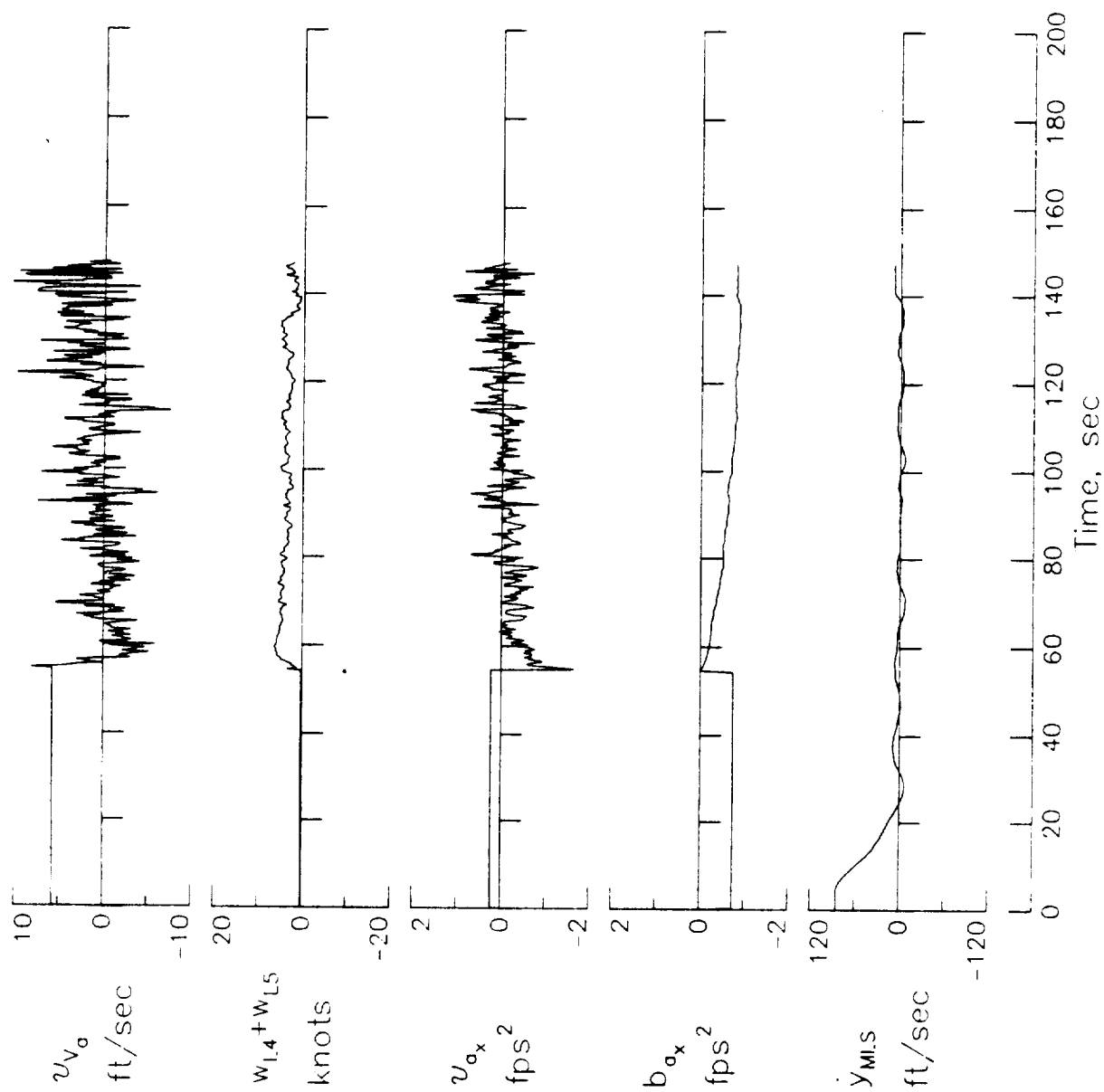


Figure 19. Continued

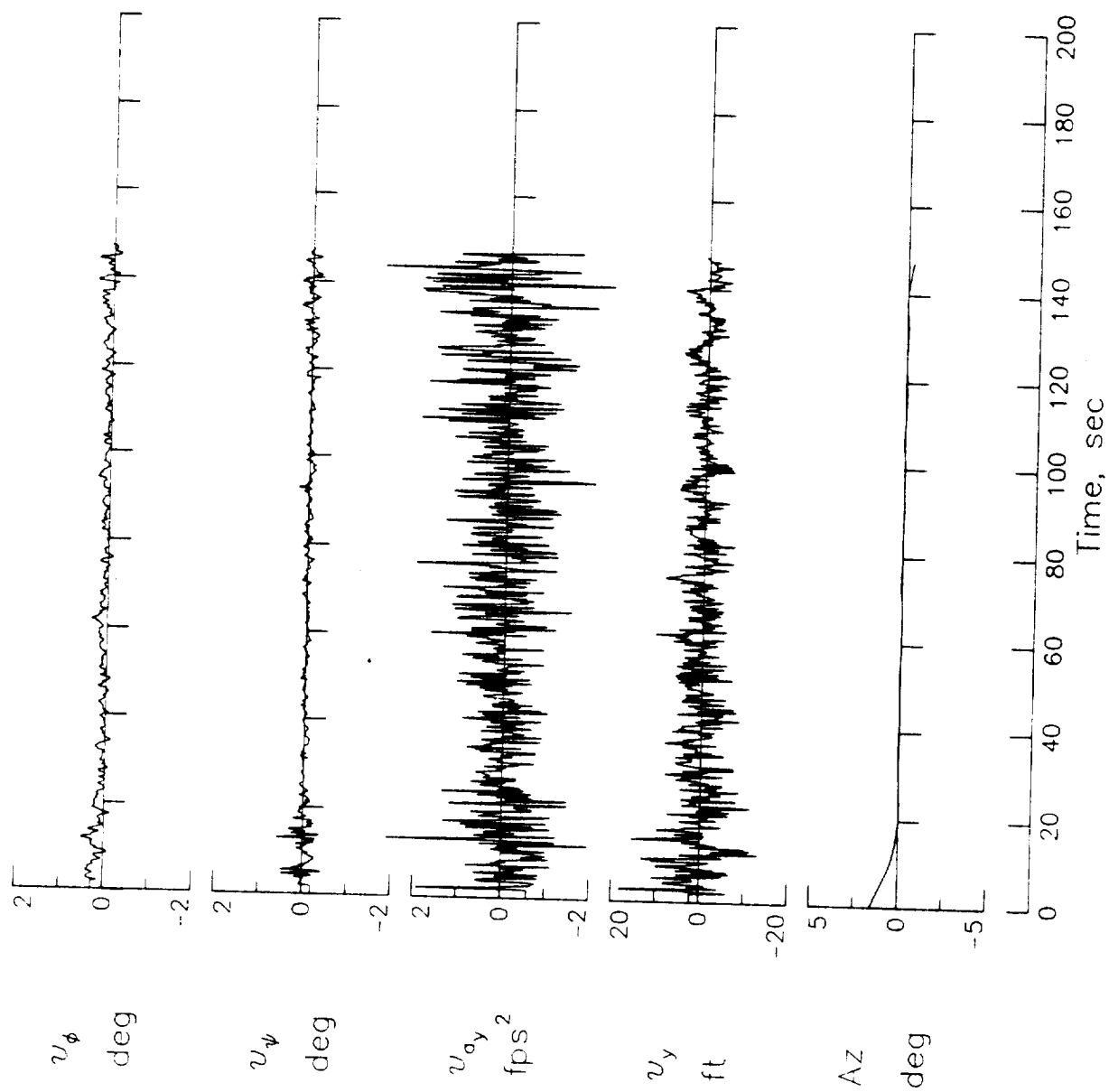


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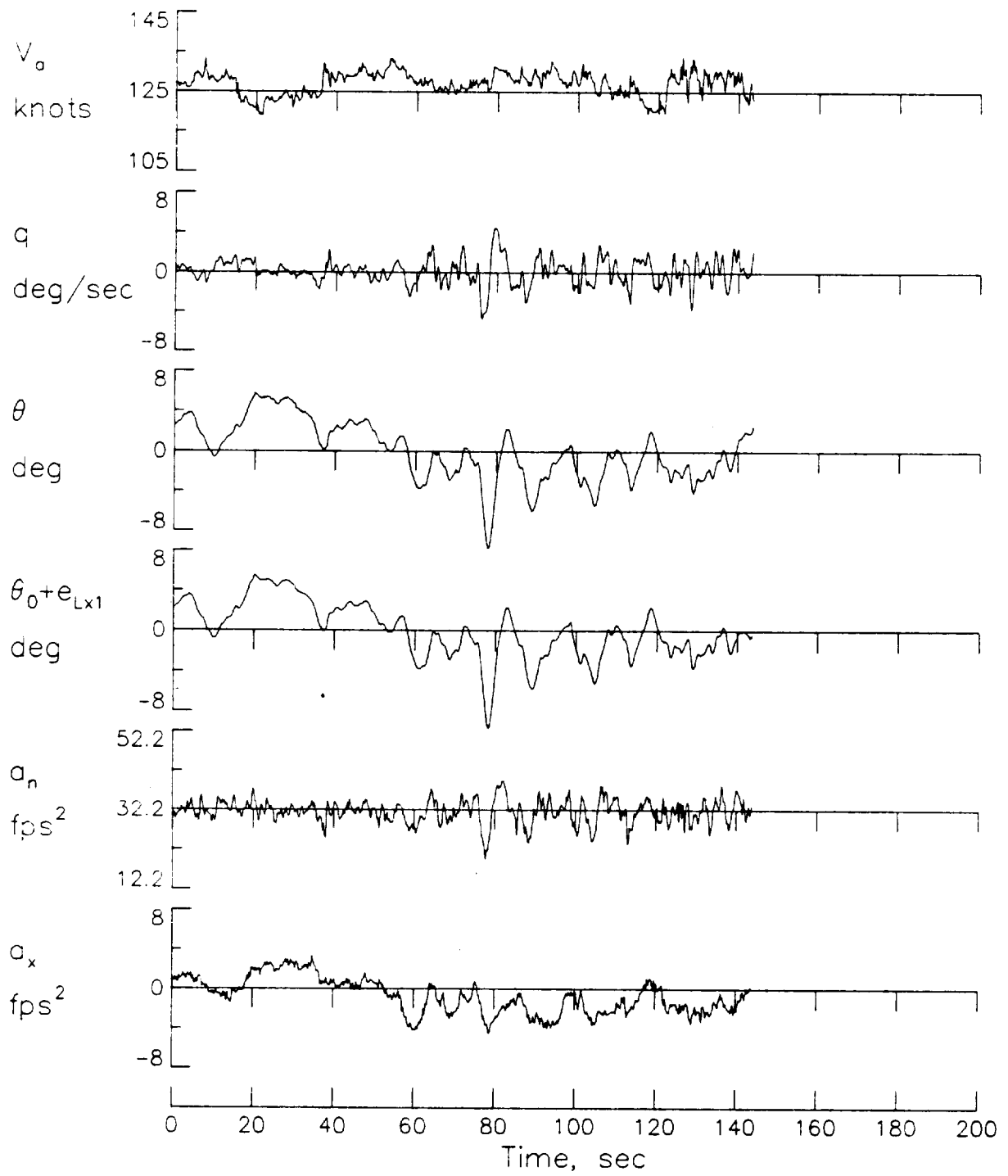


Figure 20. Flight Data for DIALS Flight Test
R357, Run 10

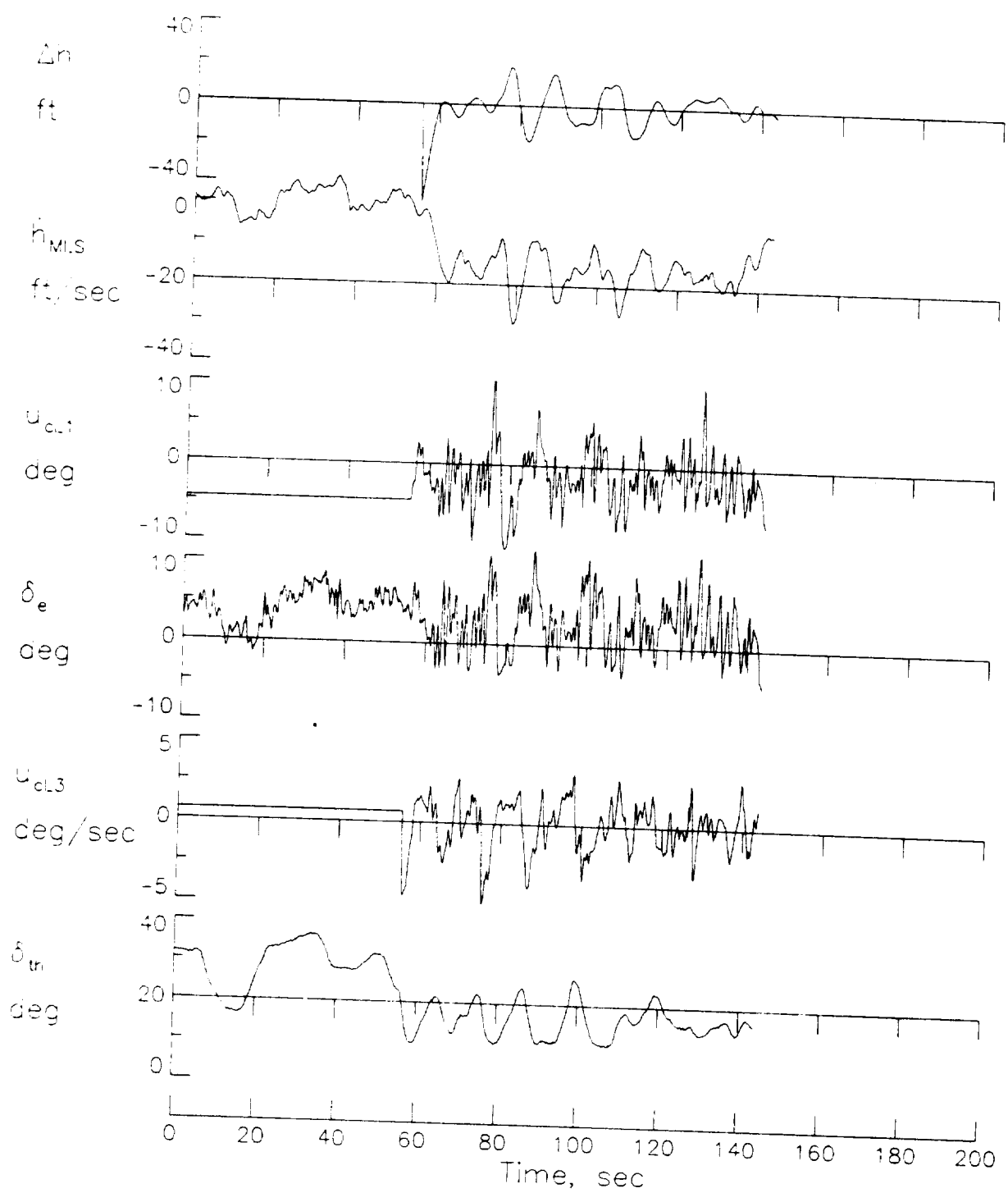


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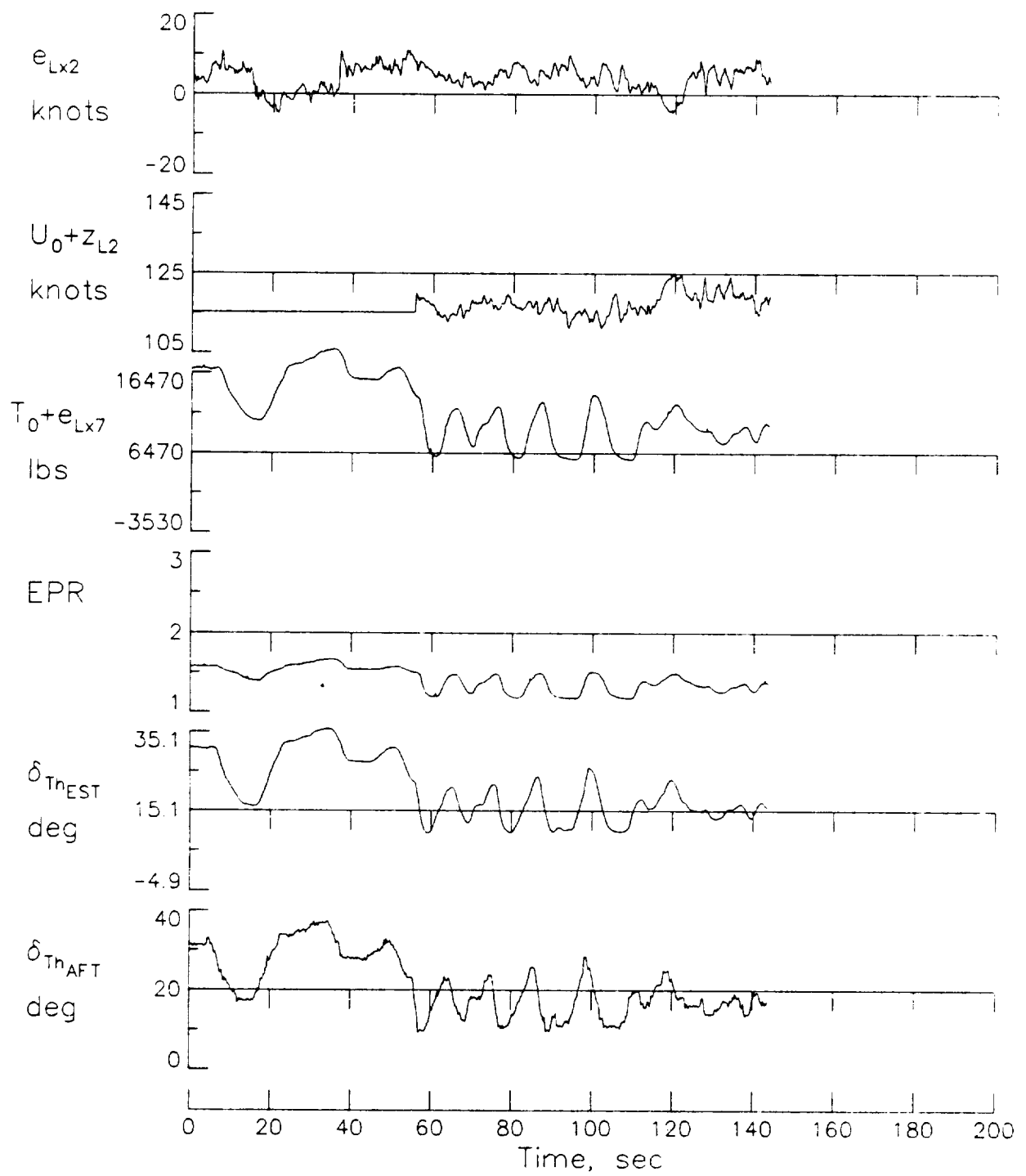


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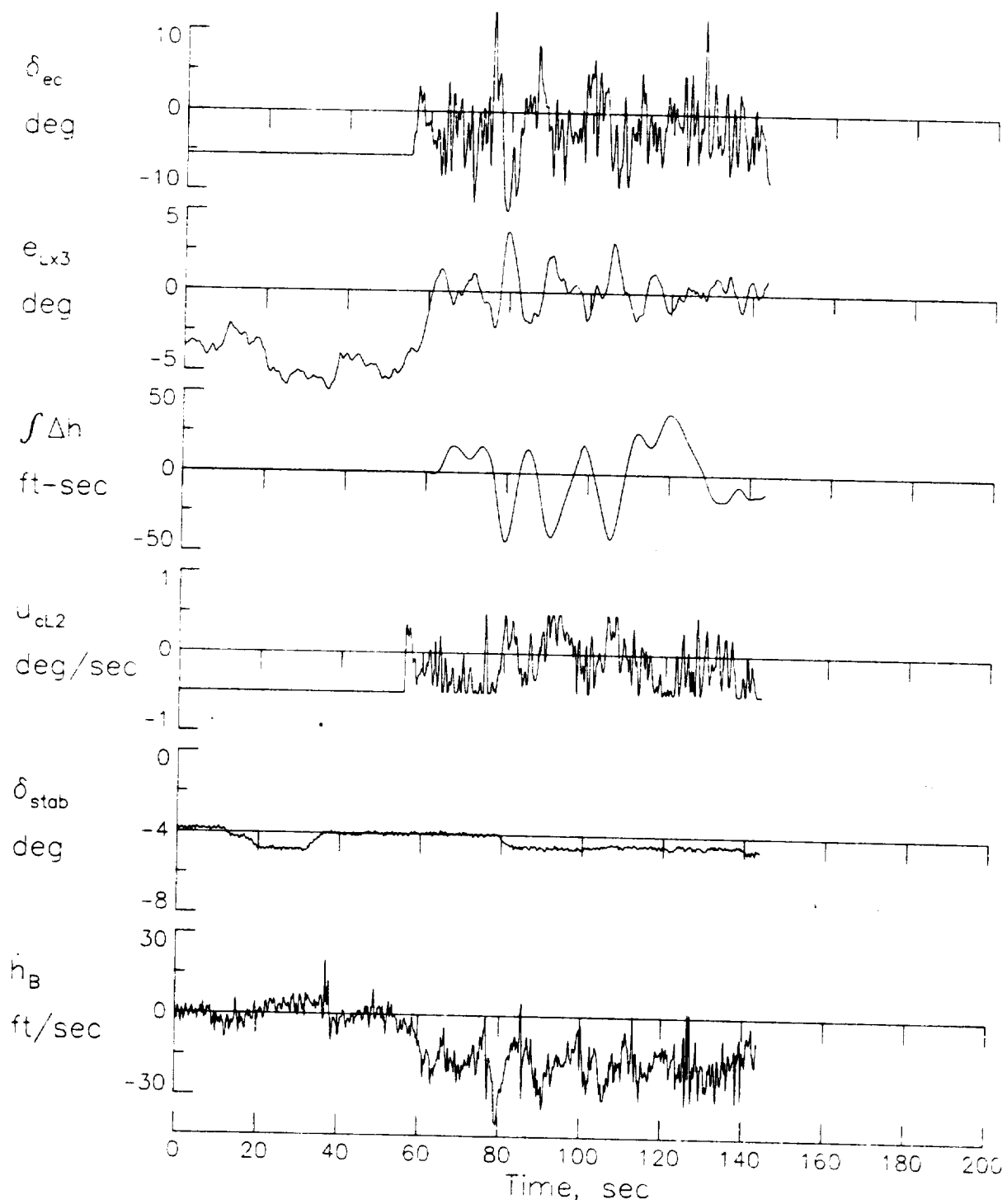


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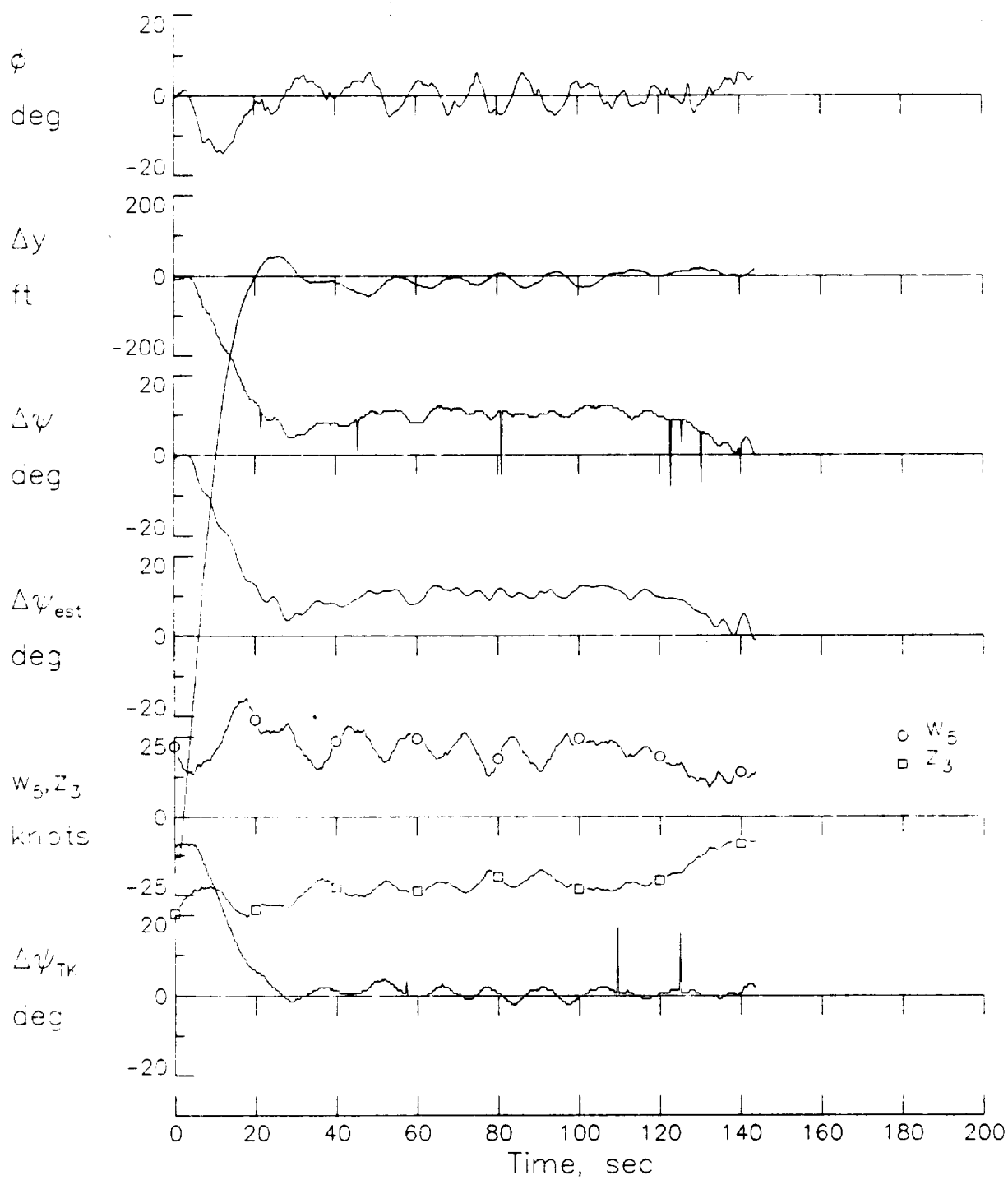


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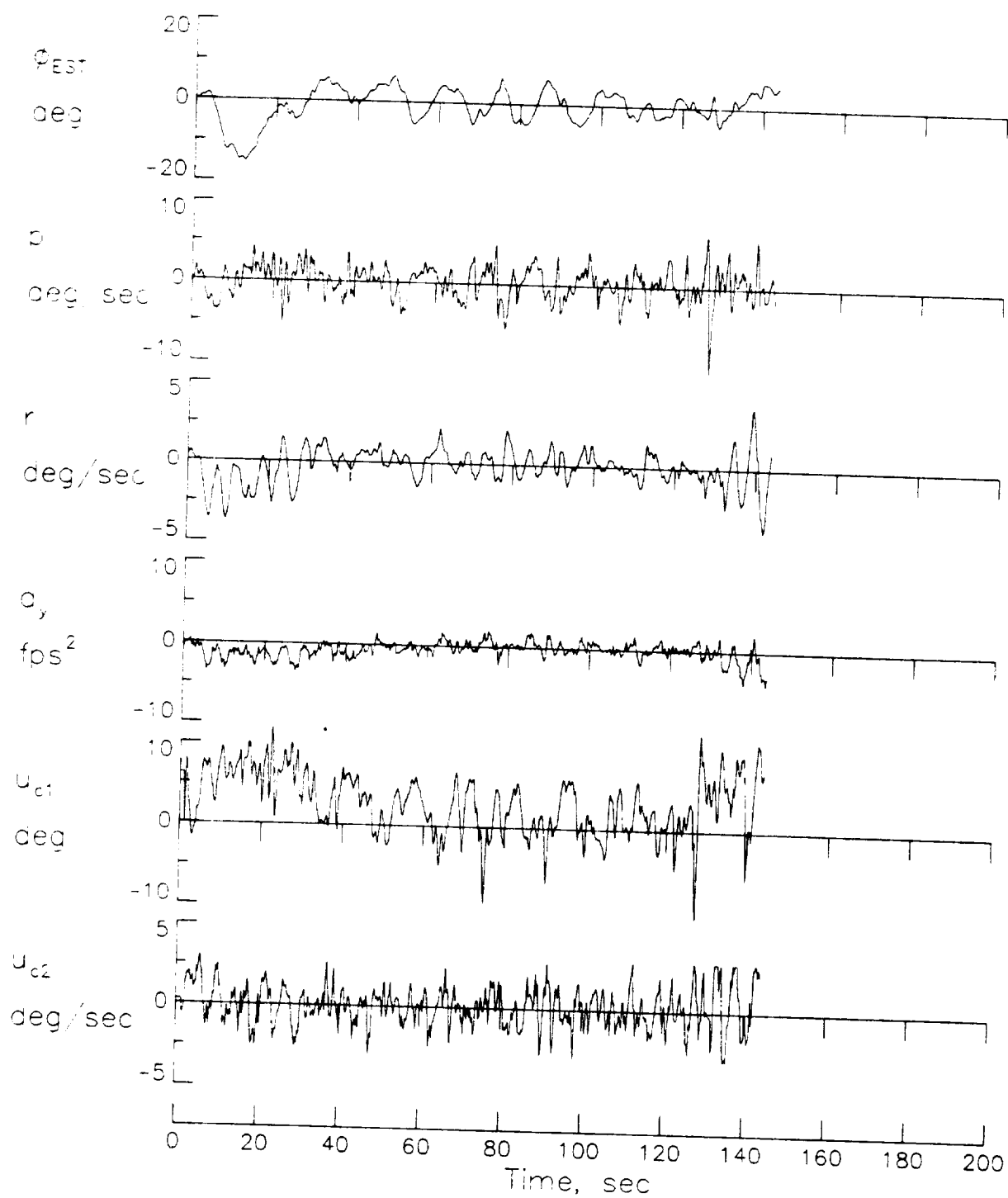


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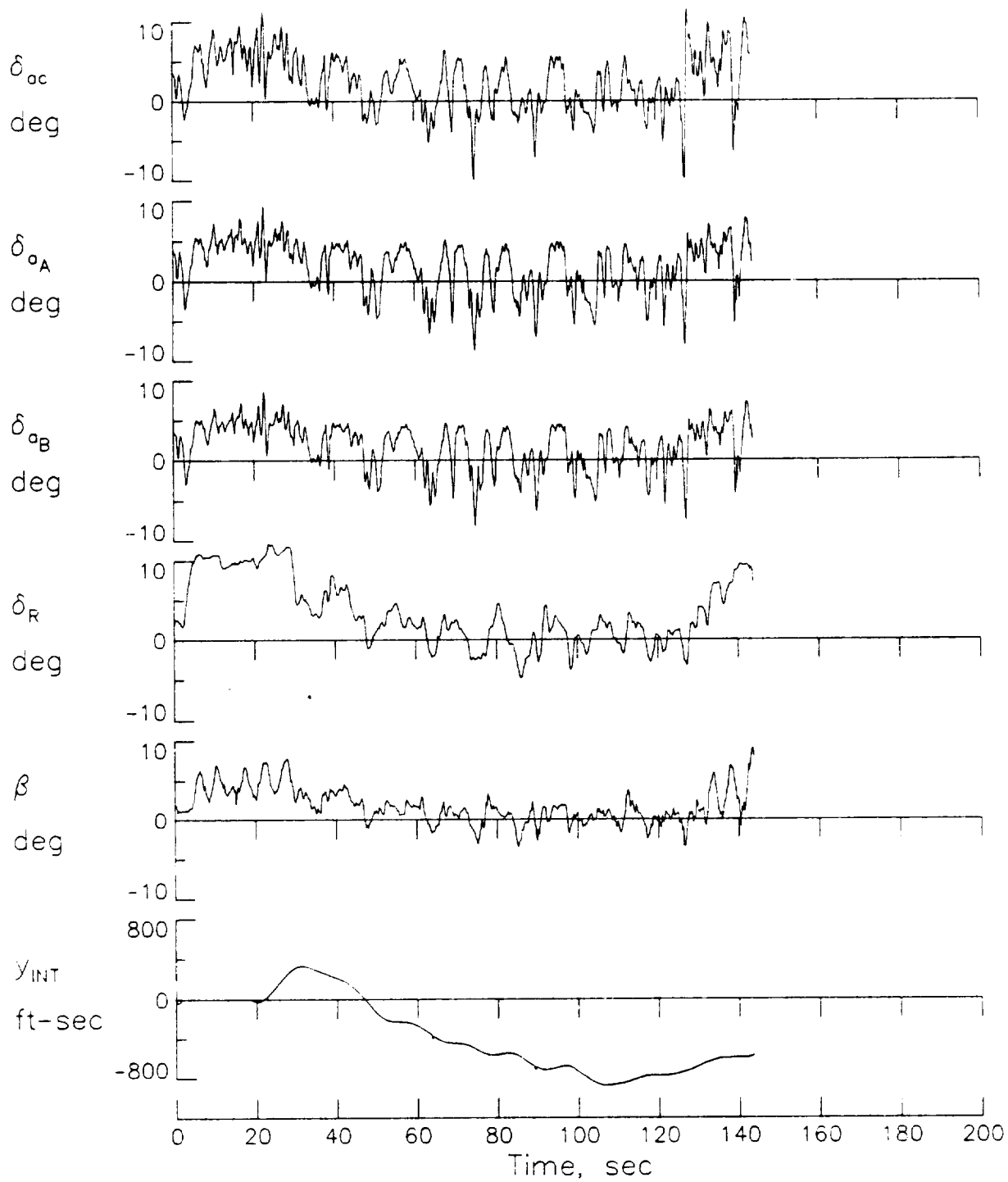


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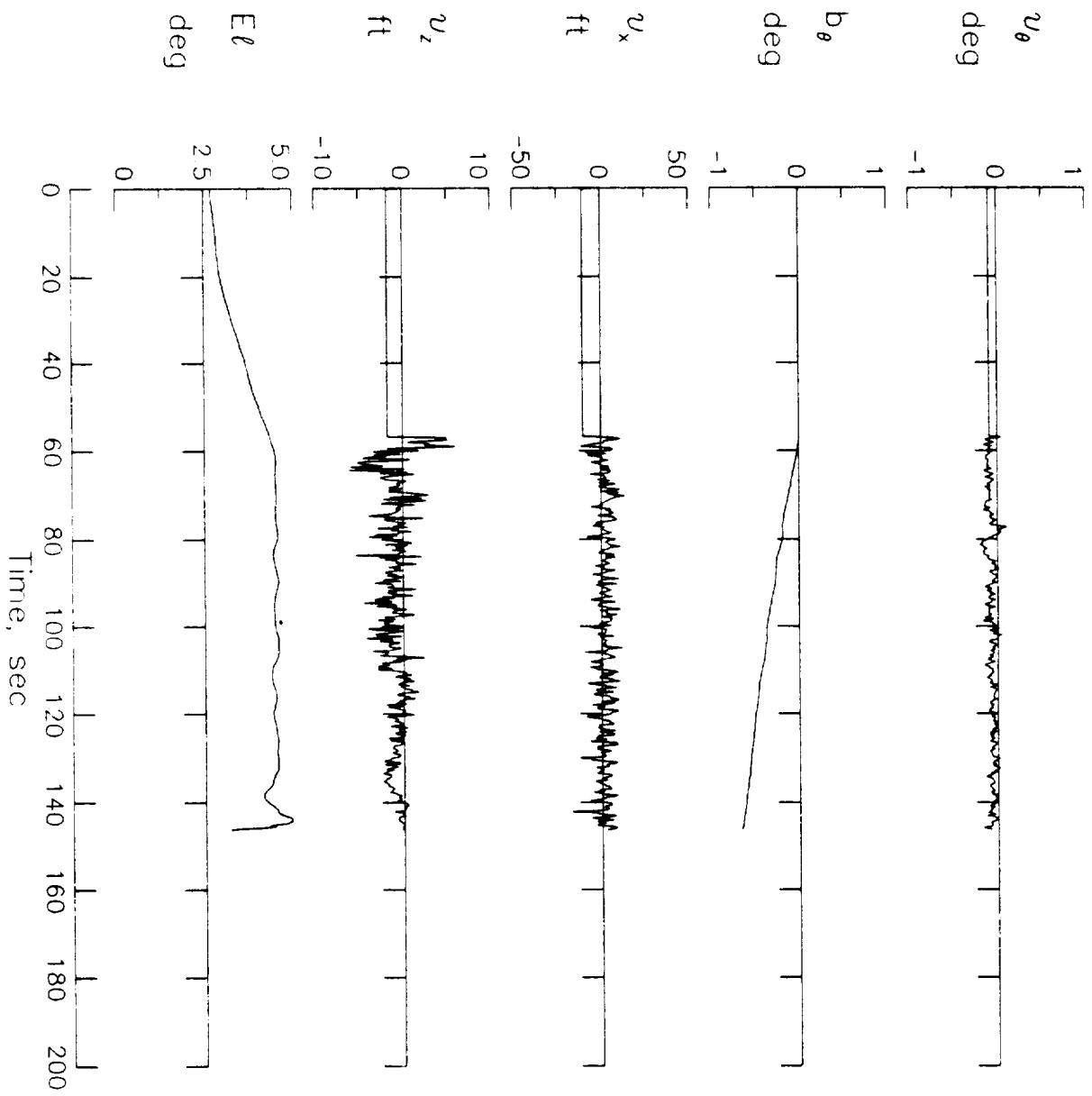


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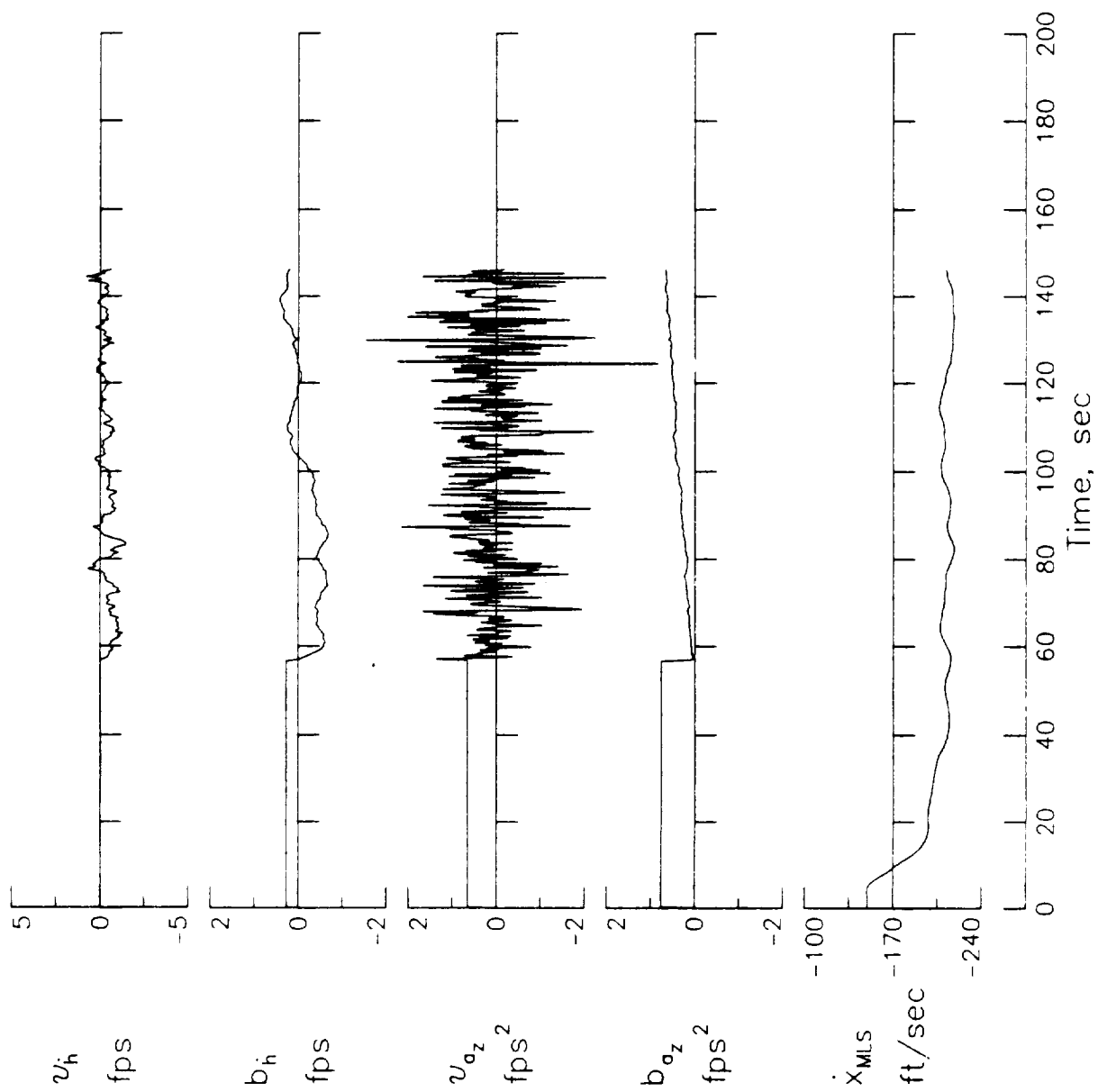


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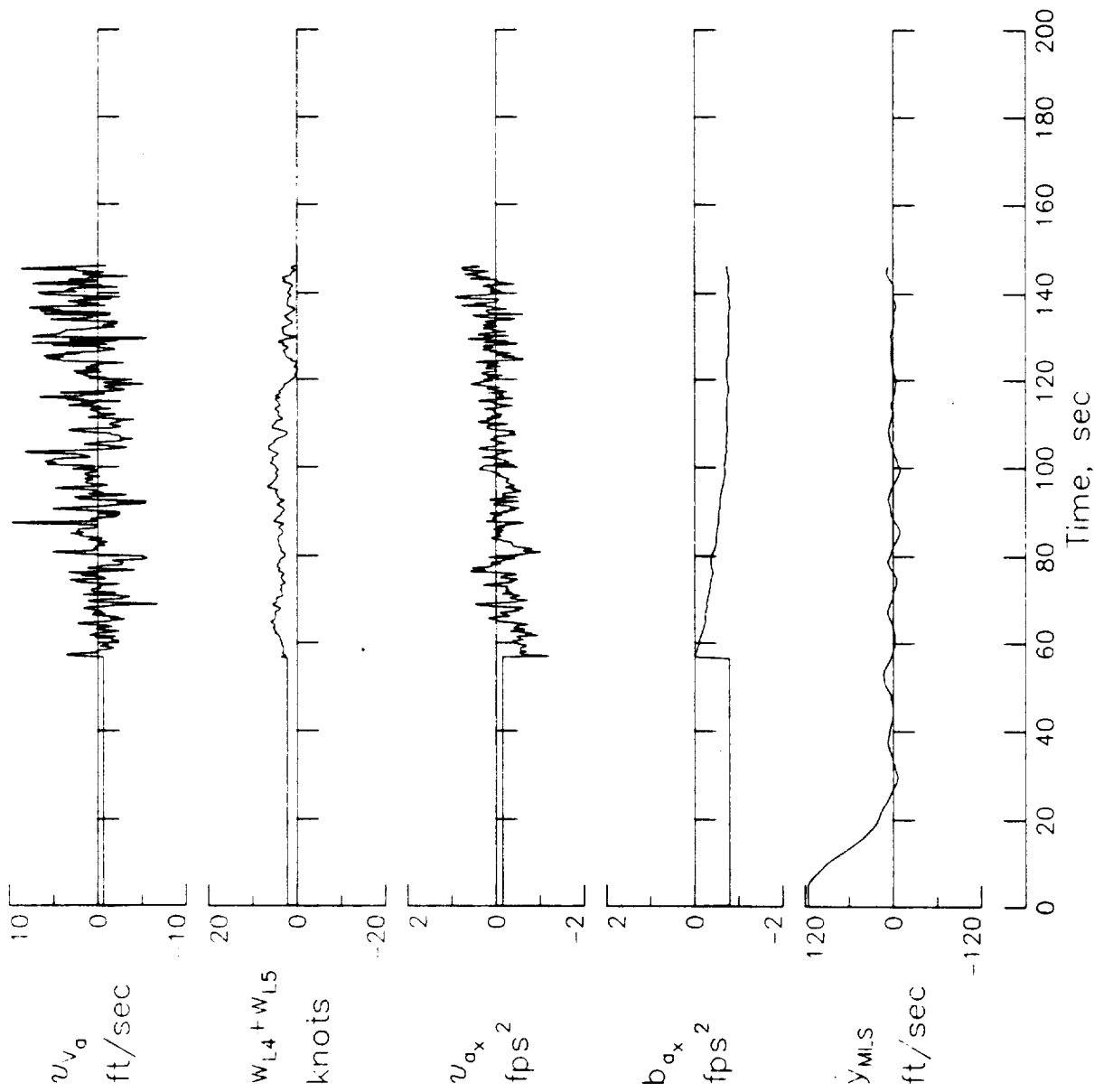


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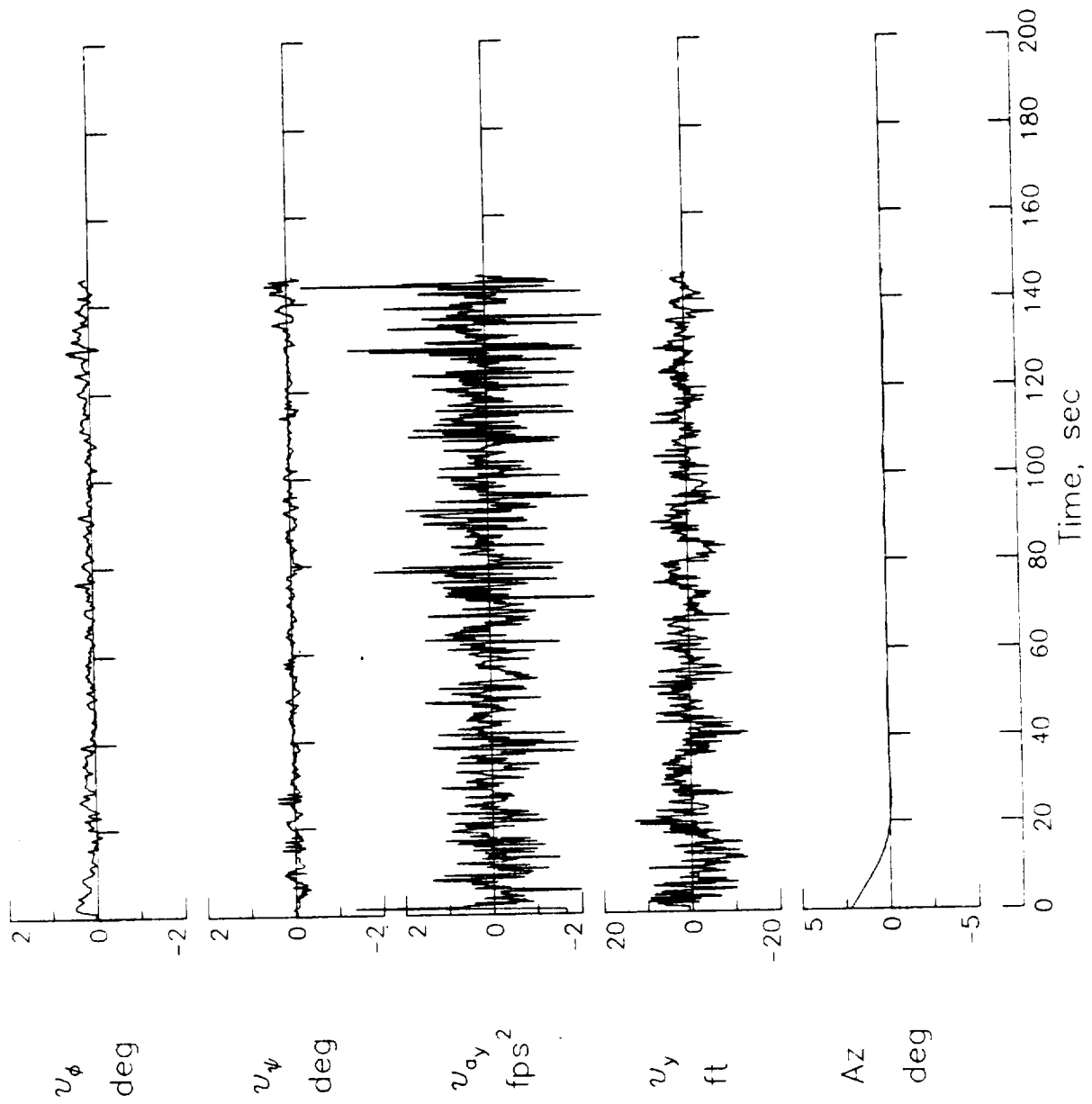


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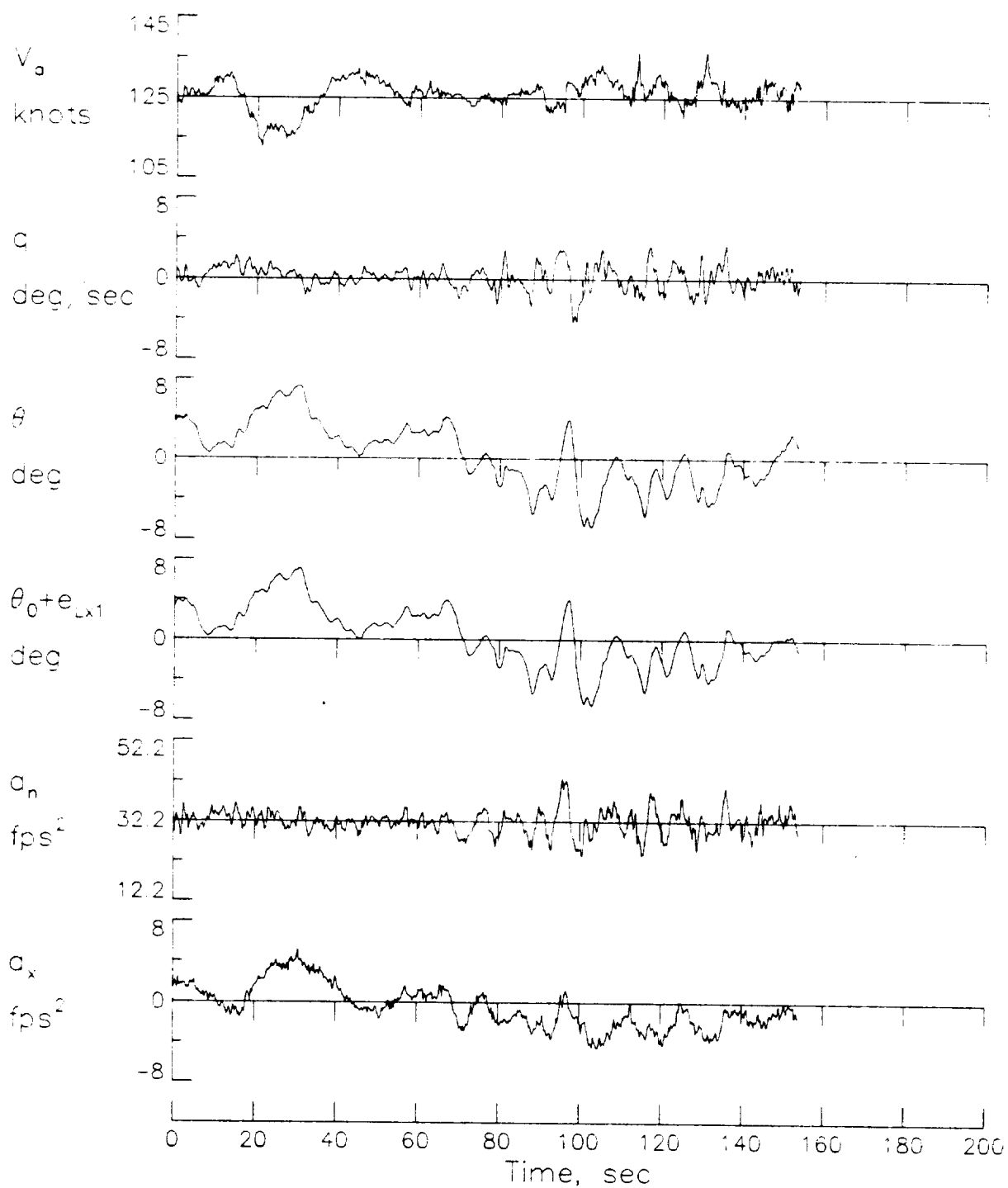


Figure 21. Flight Data for DIALS Flight Test R357, Run 11

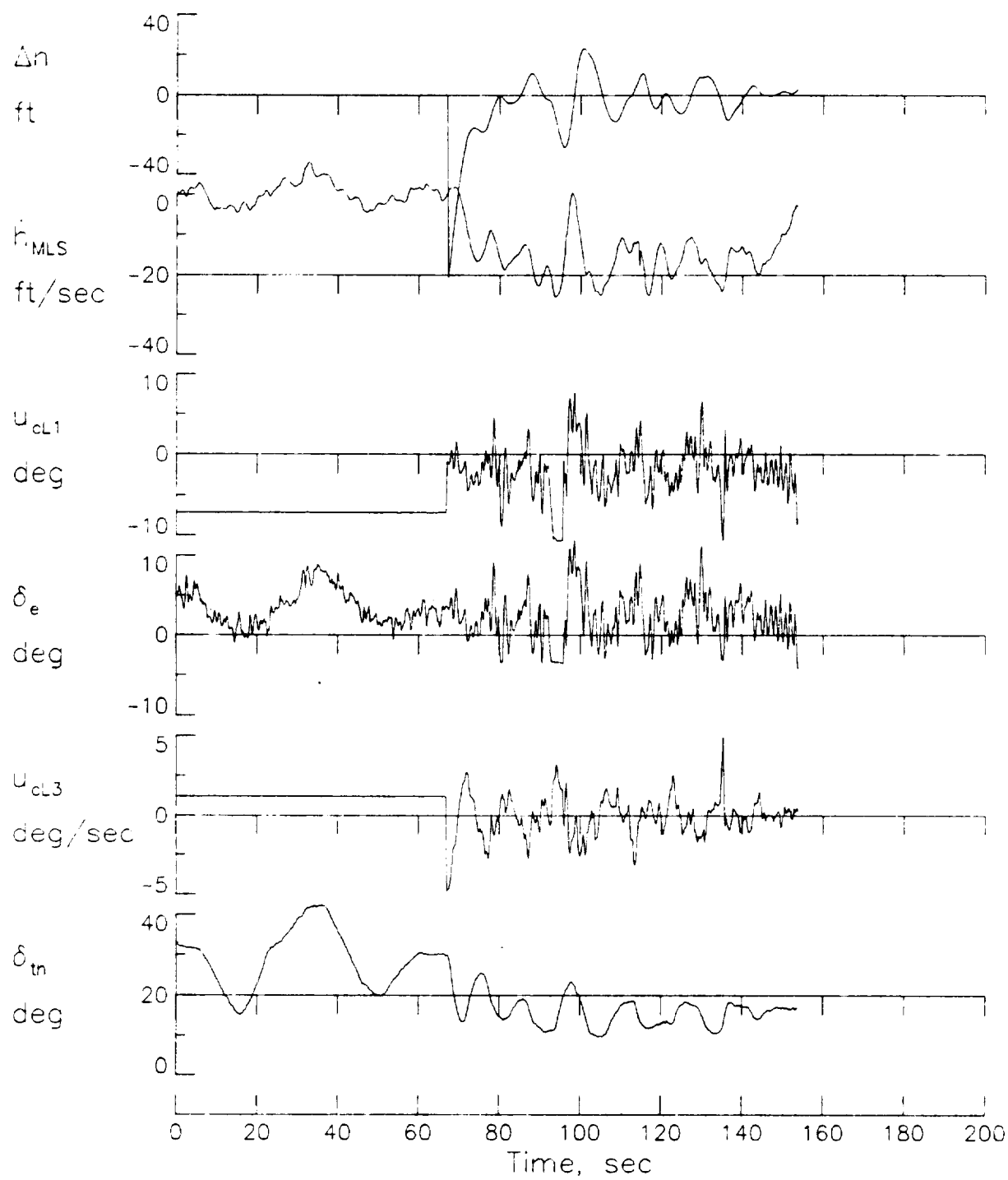


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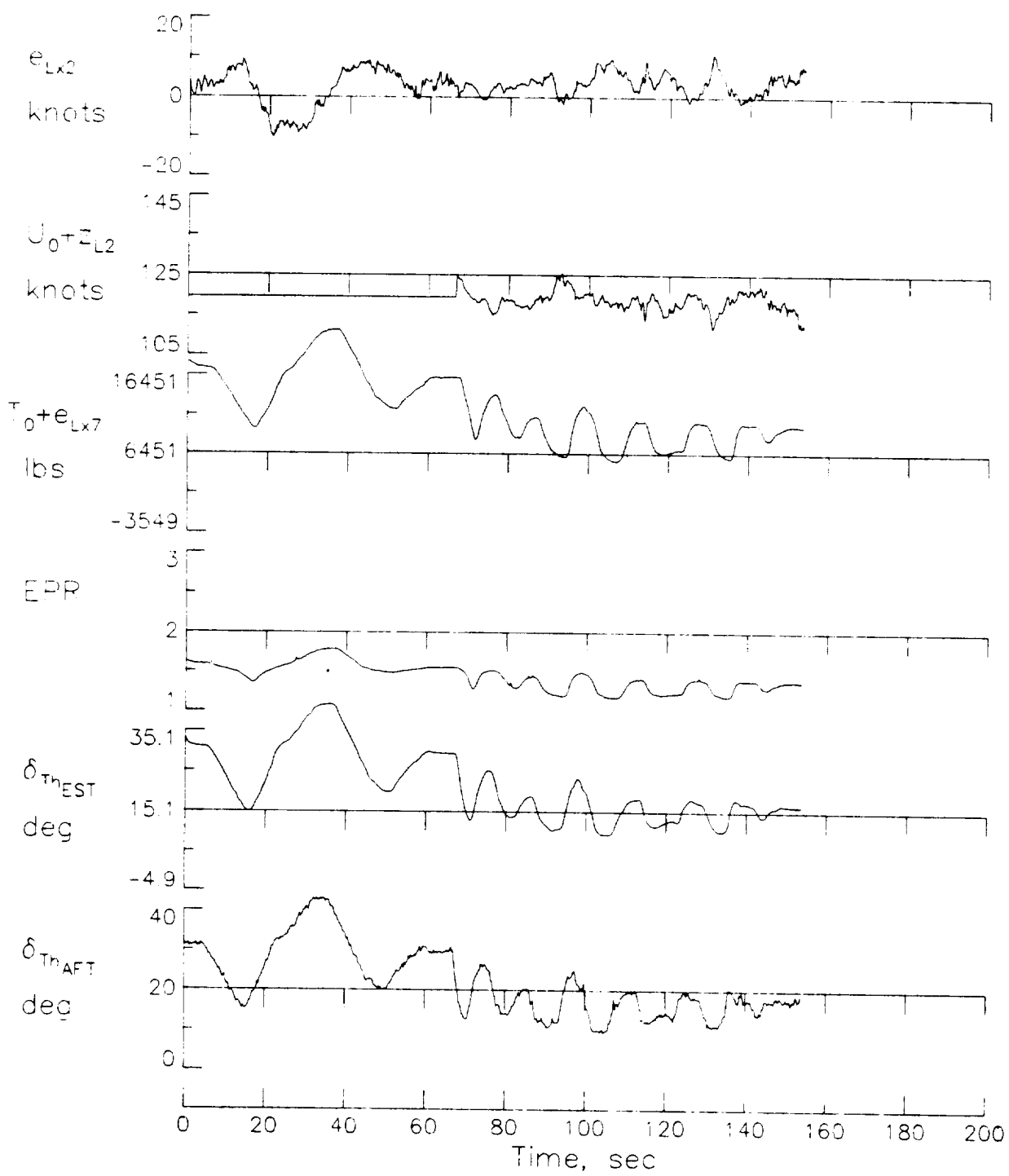


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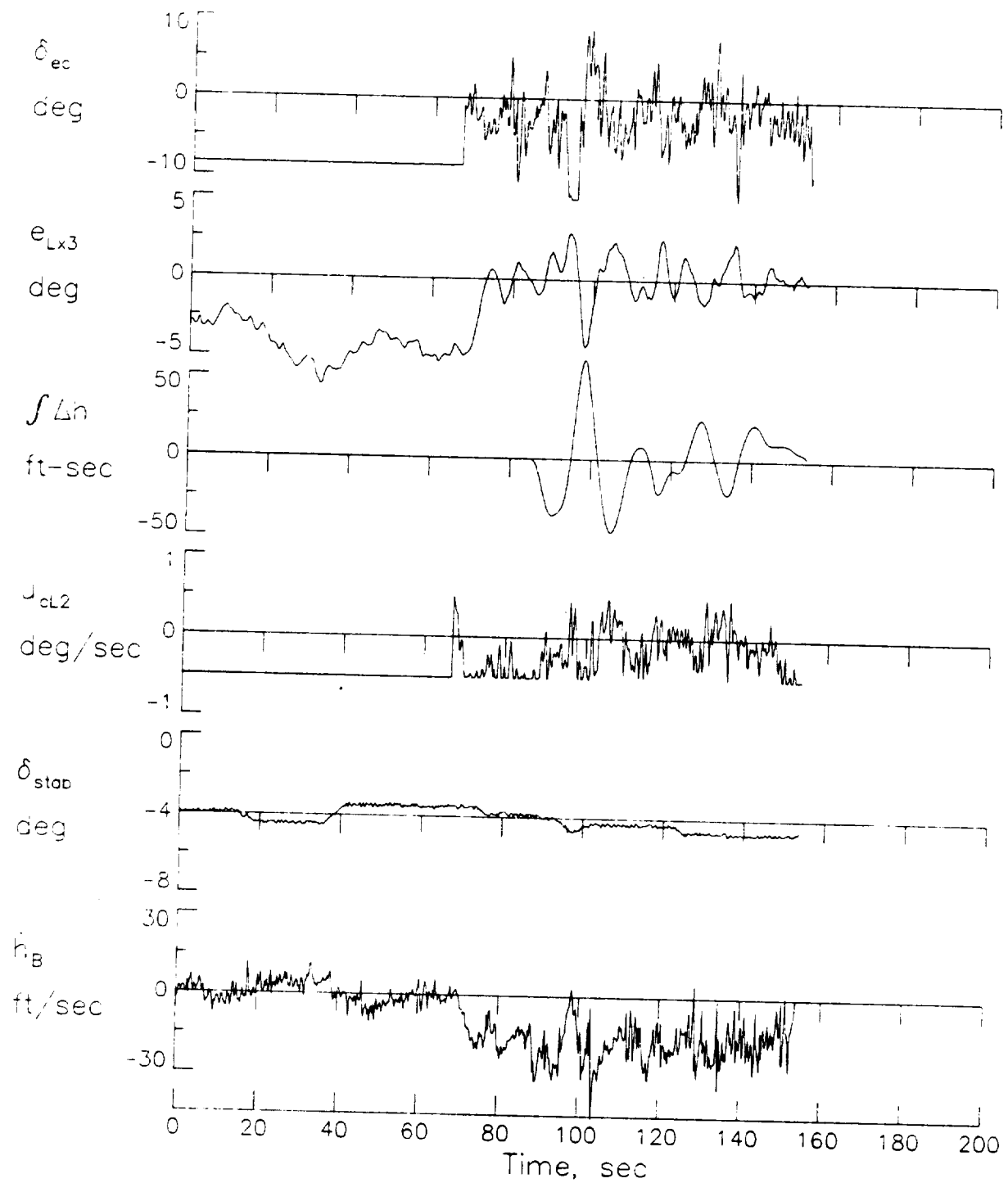


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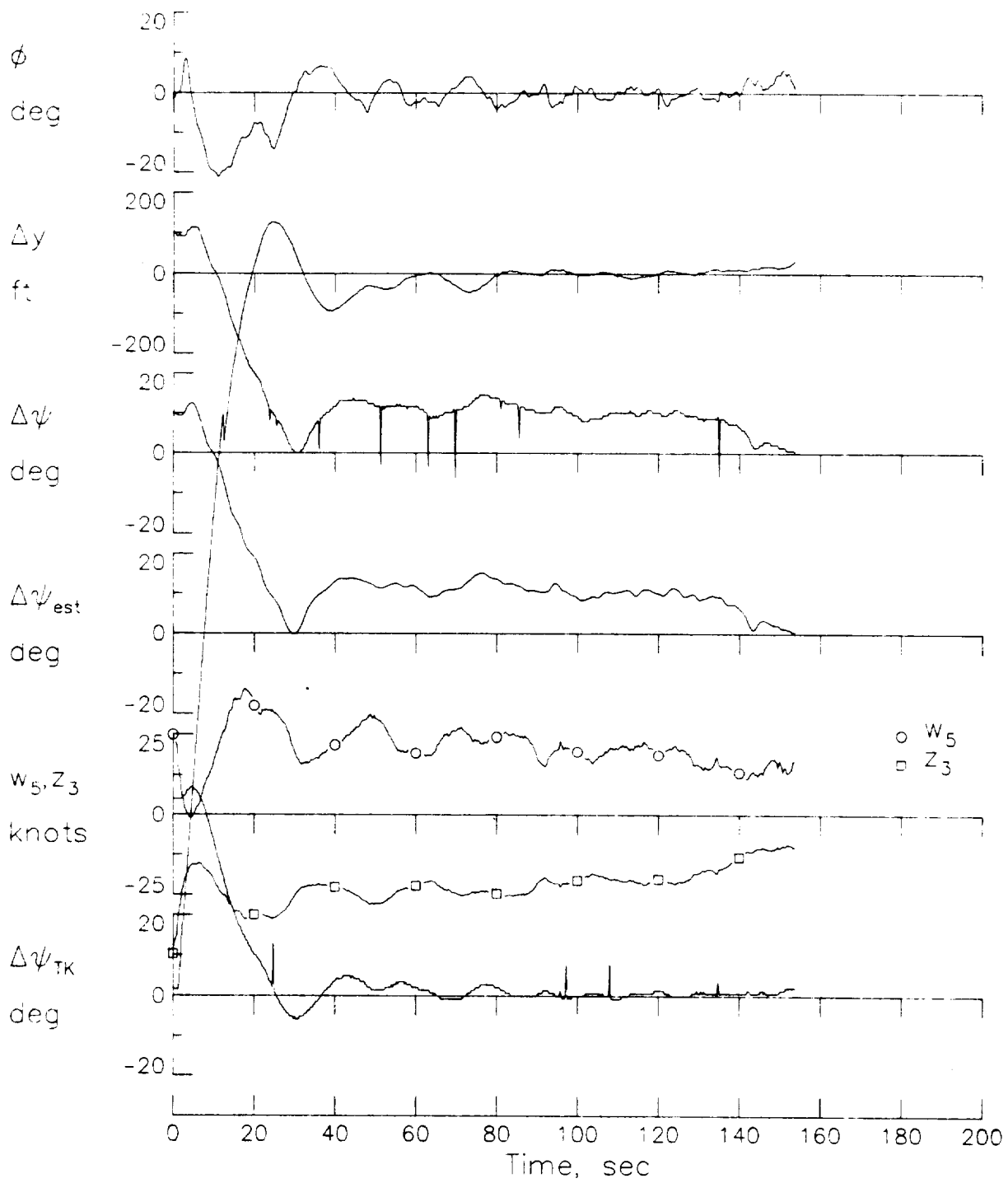


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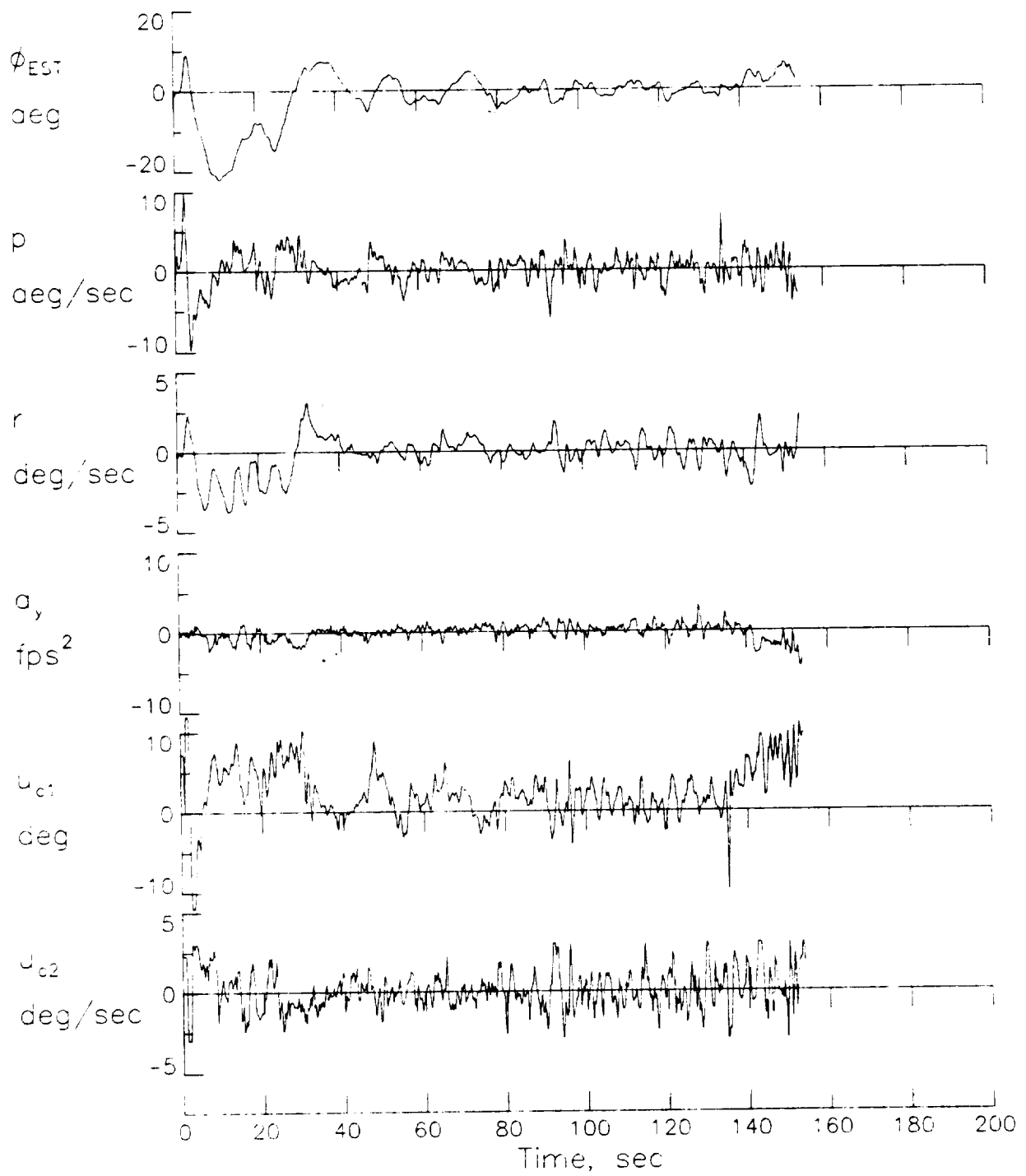


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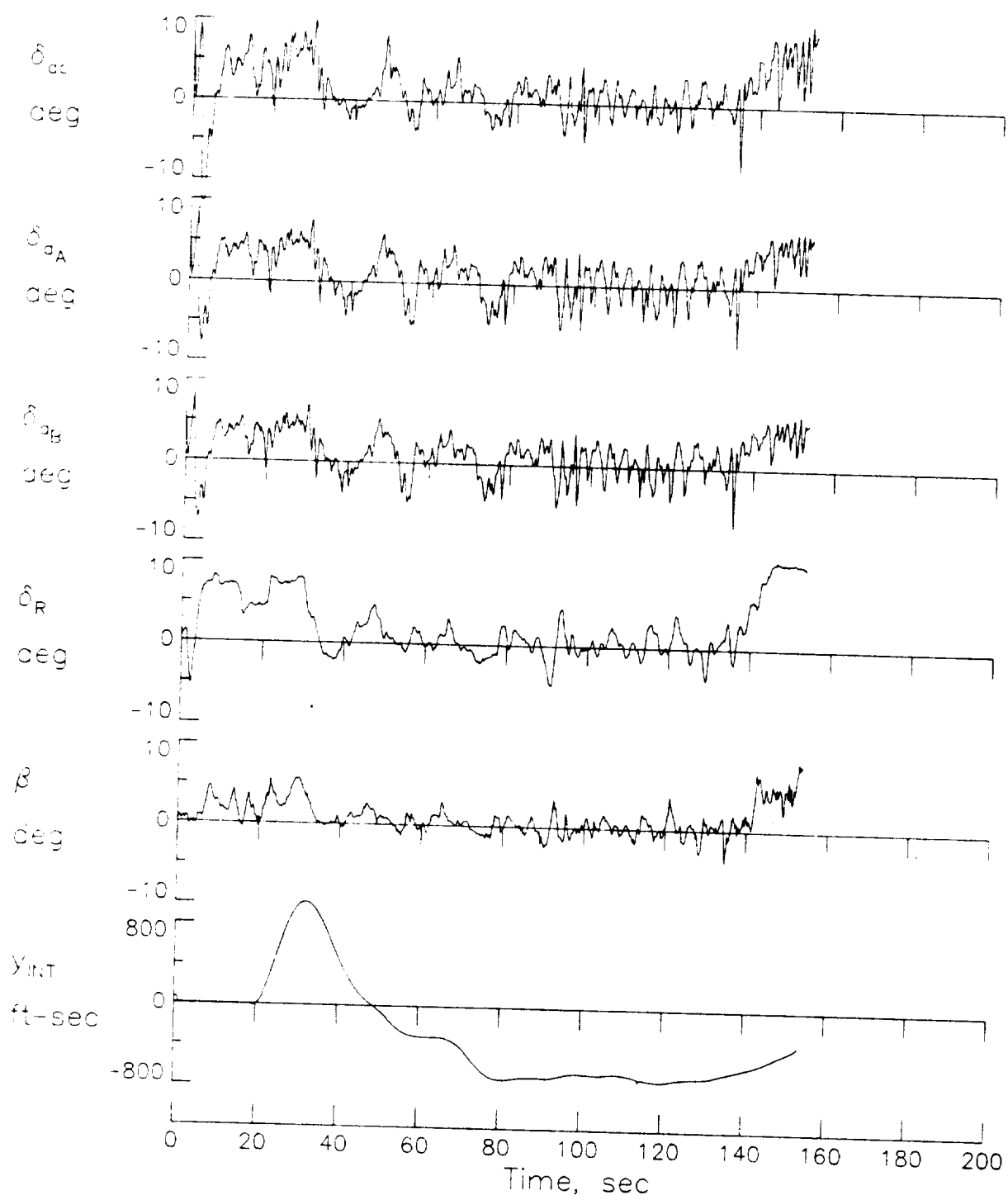


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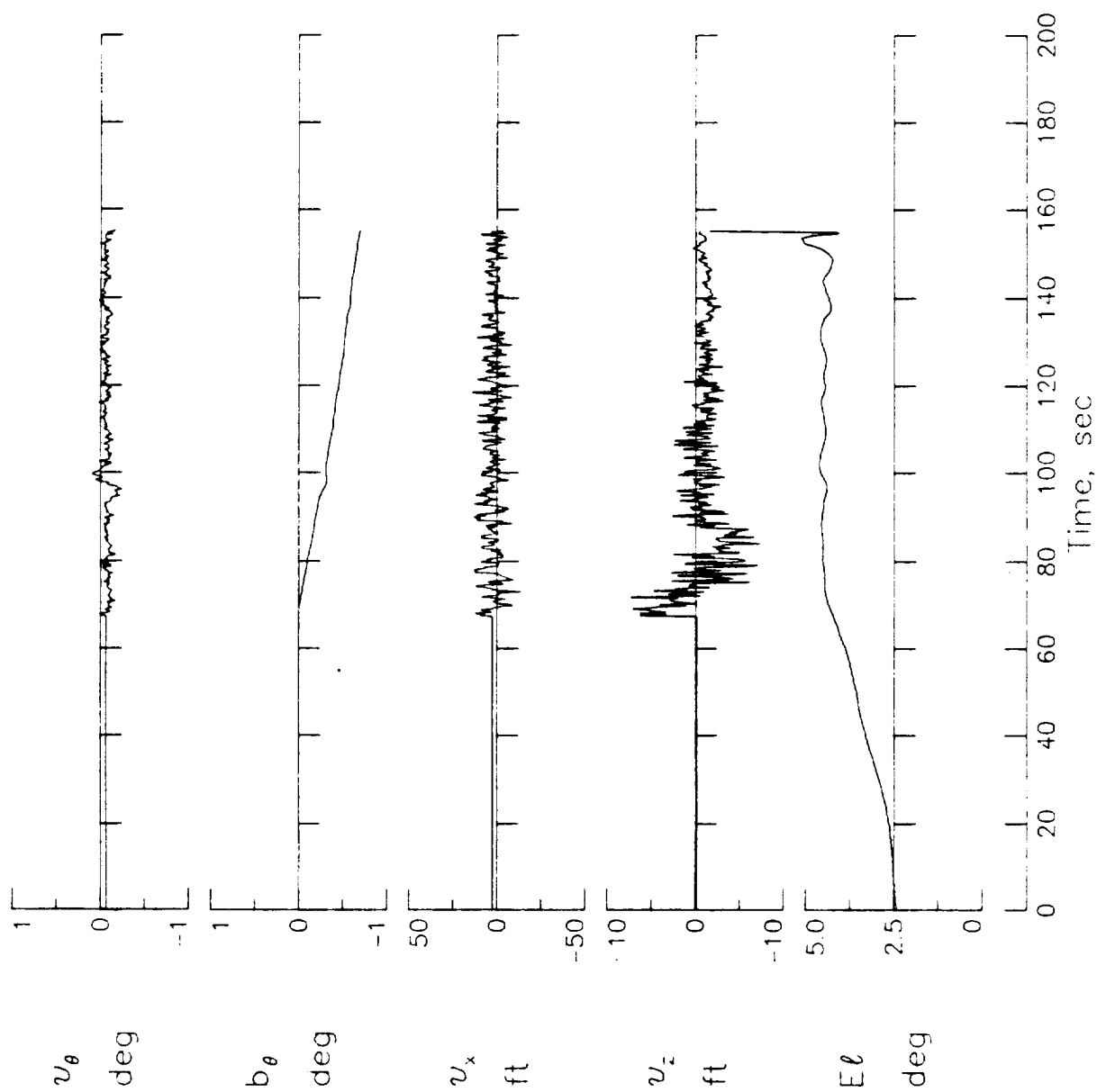


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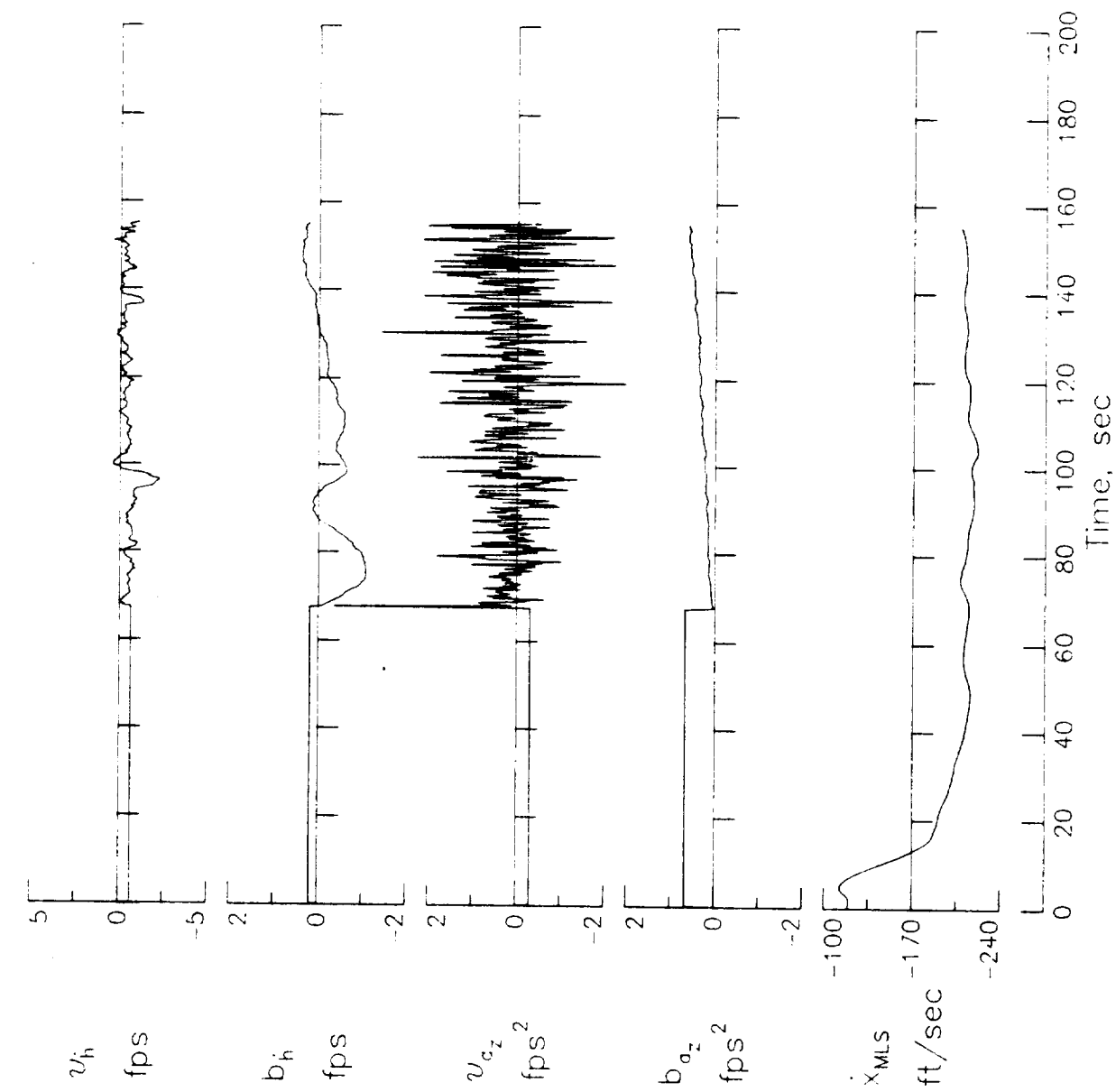


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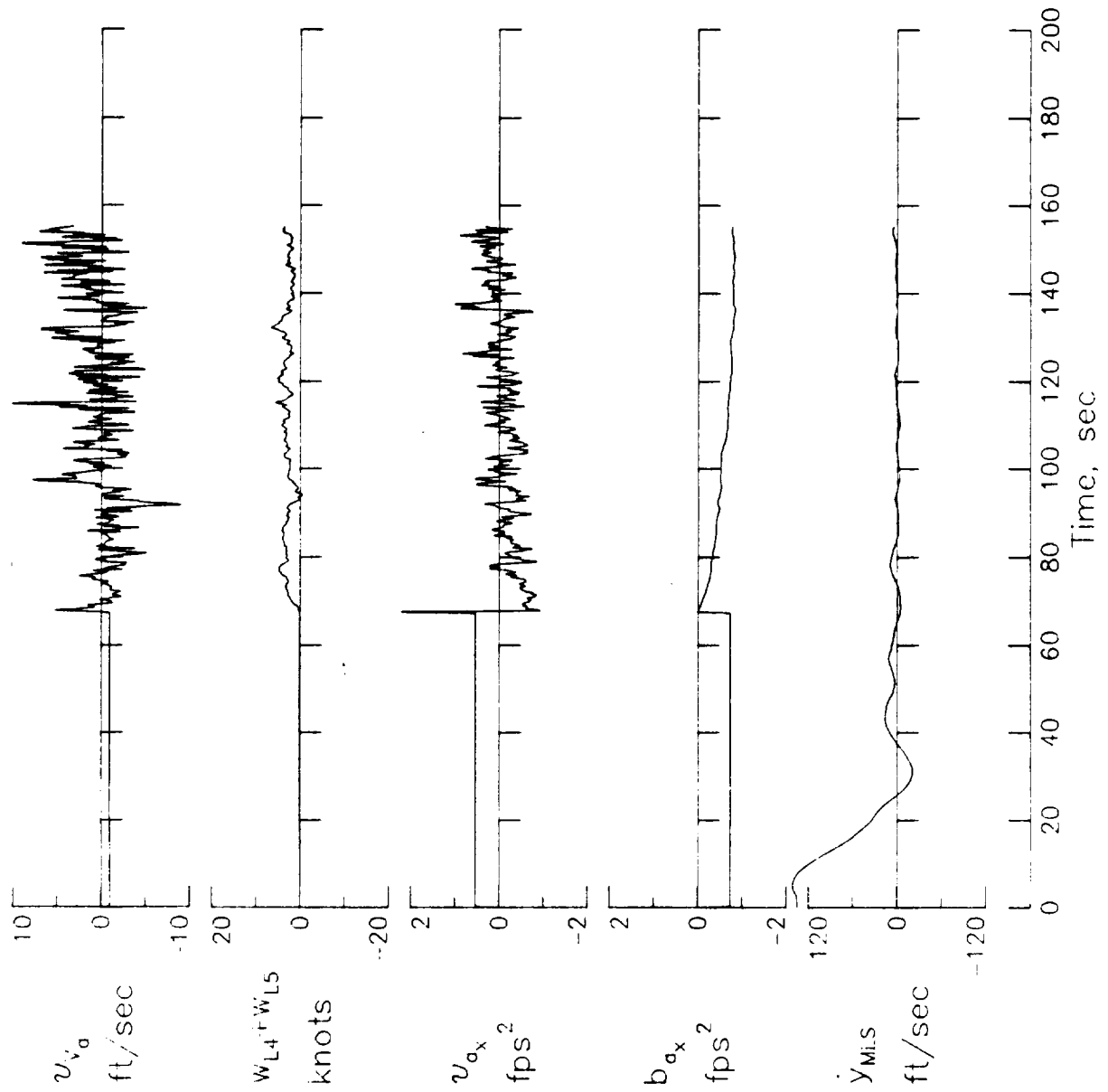


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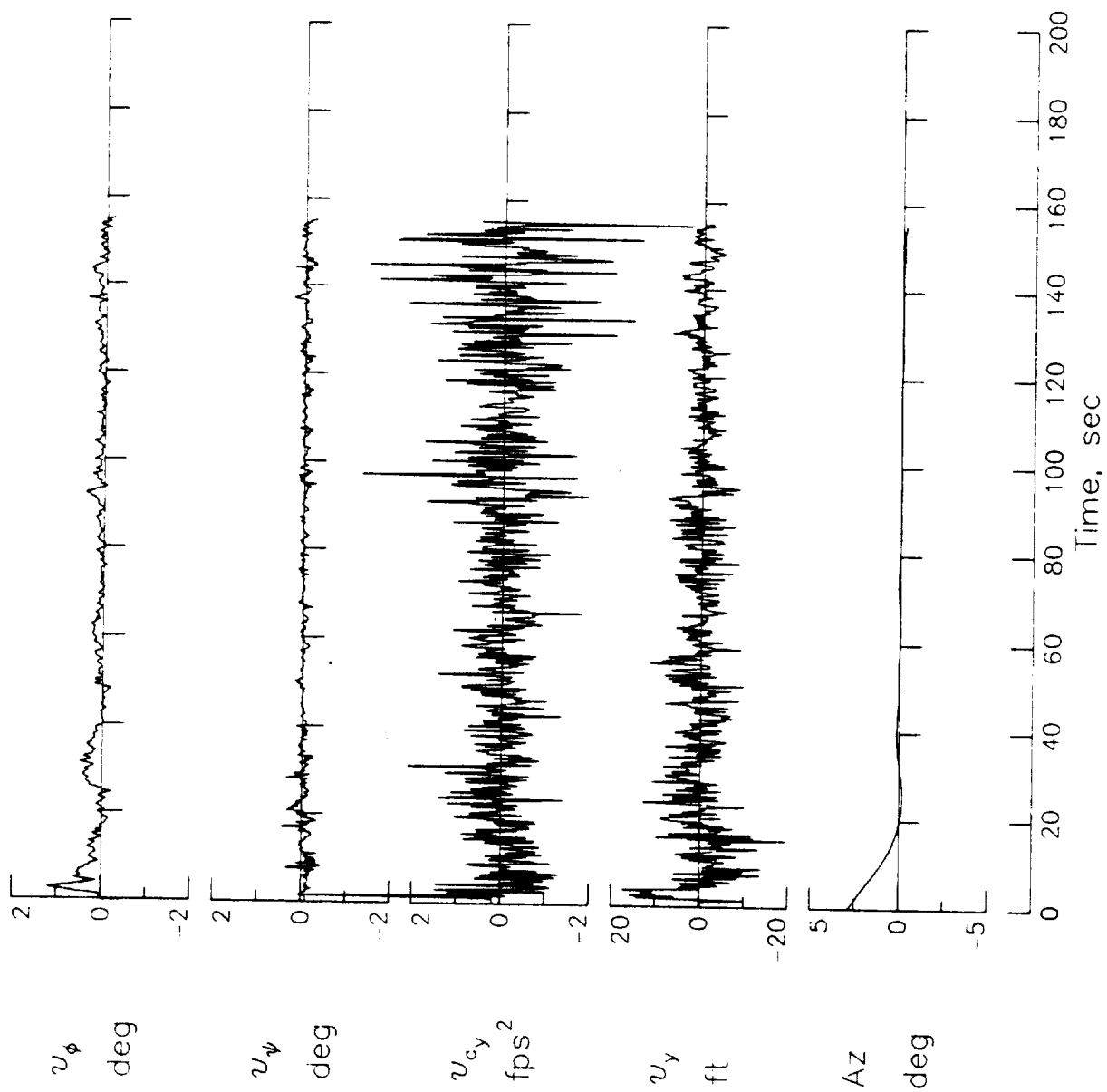


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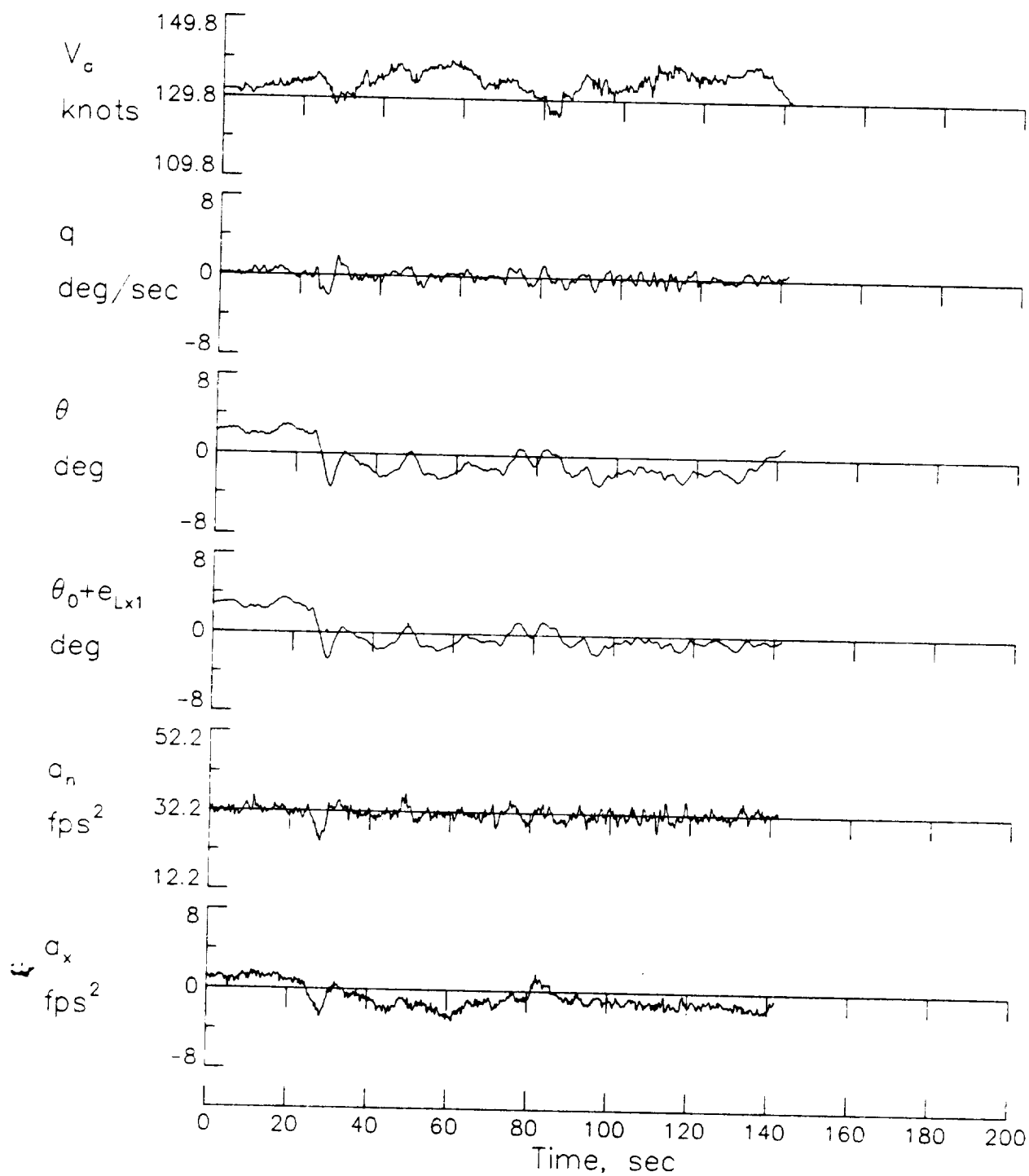


Figure 22. Flight Data for DIALS Flight Test R361, Run 7

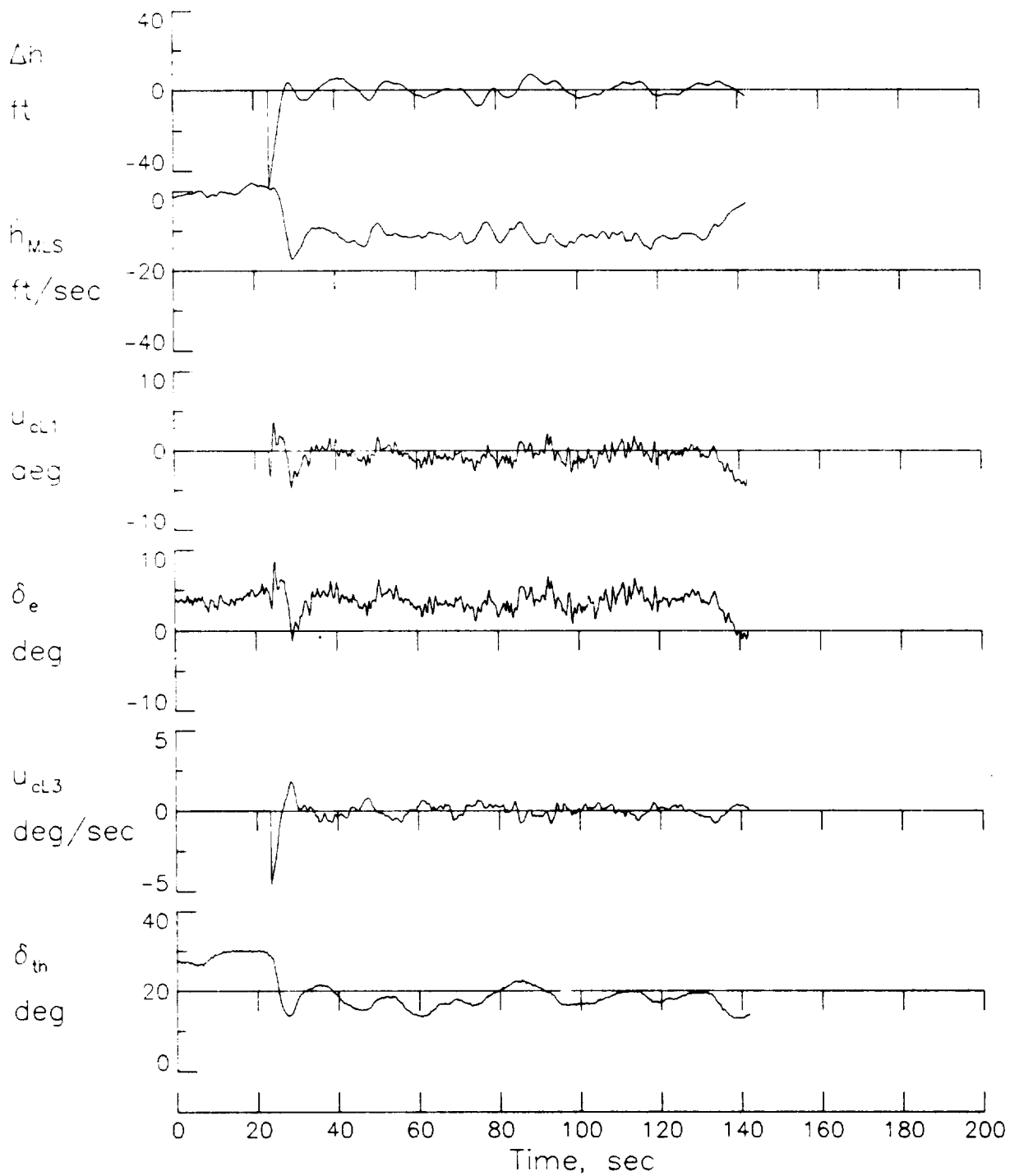


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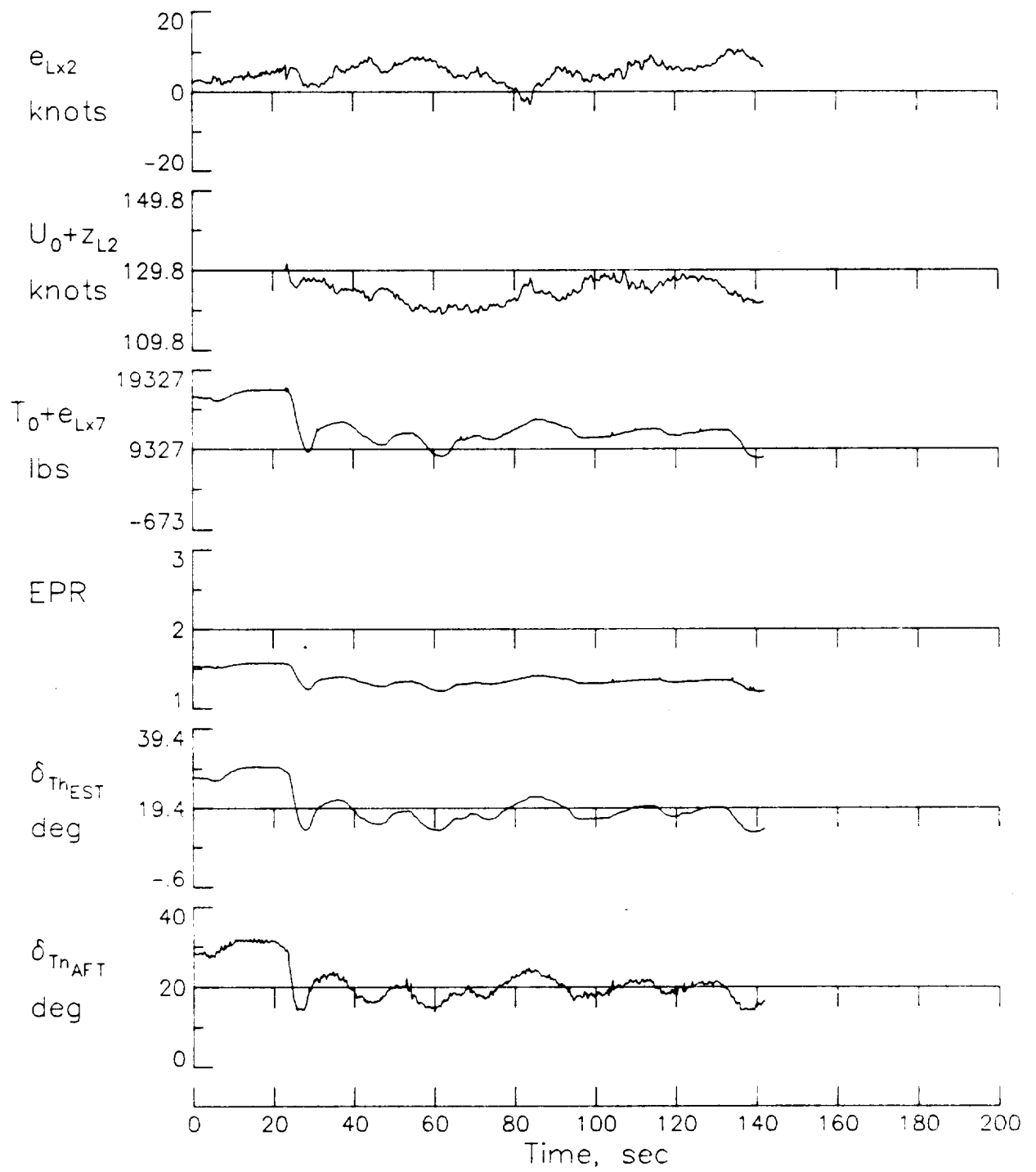


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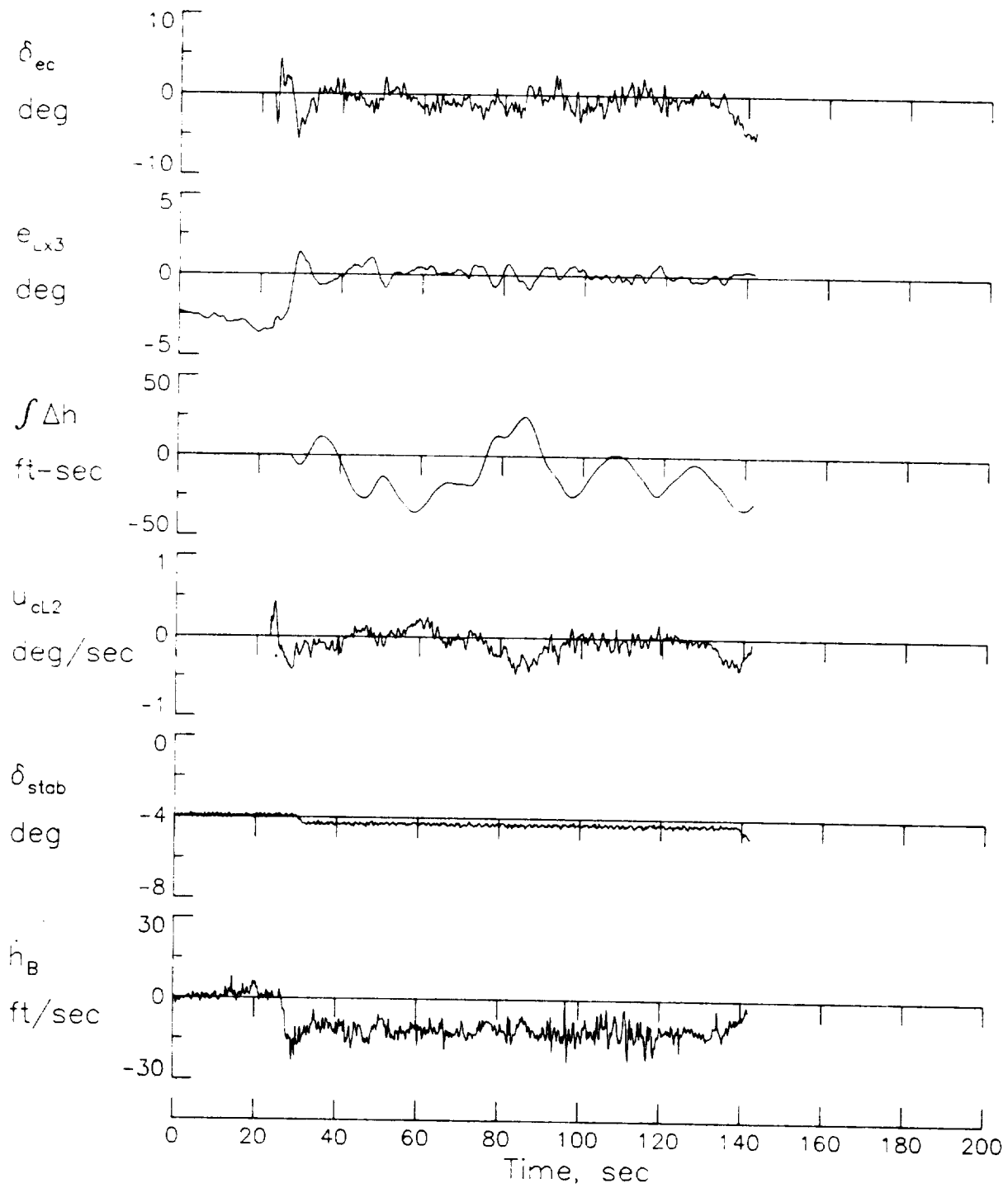


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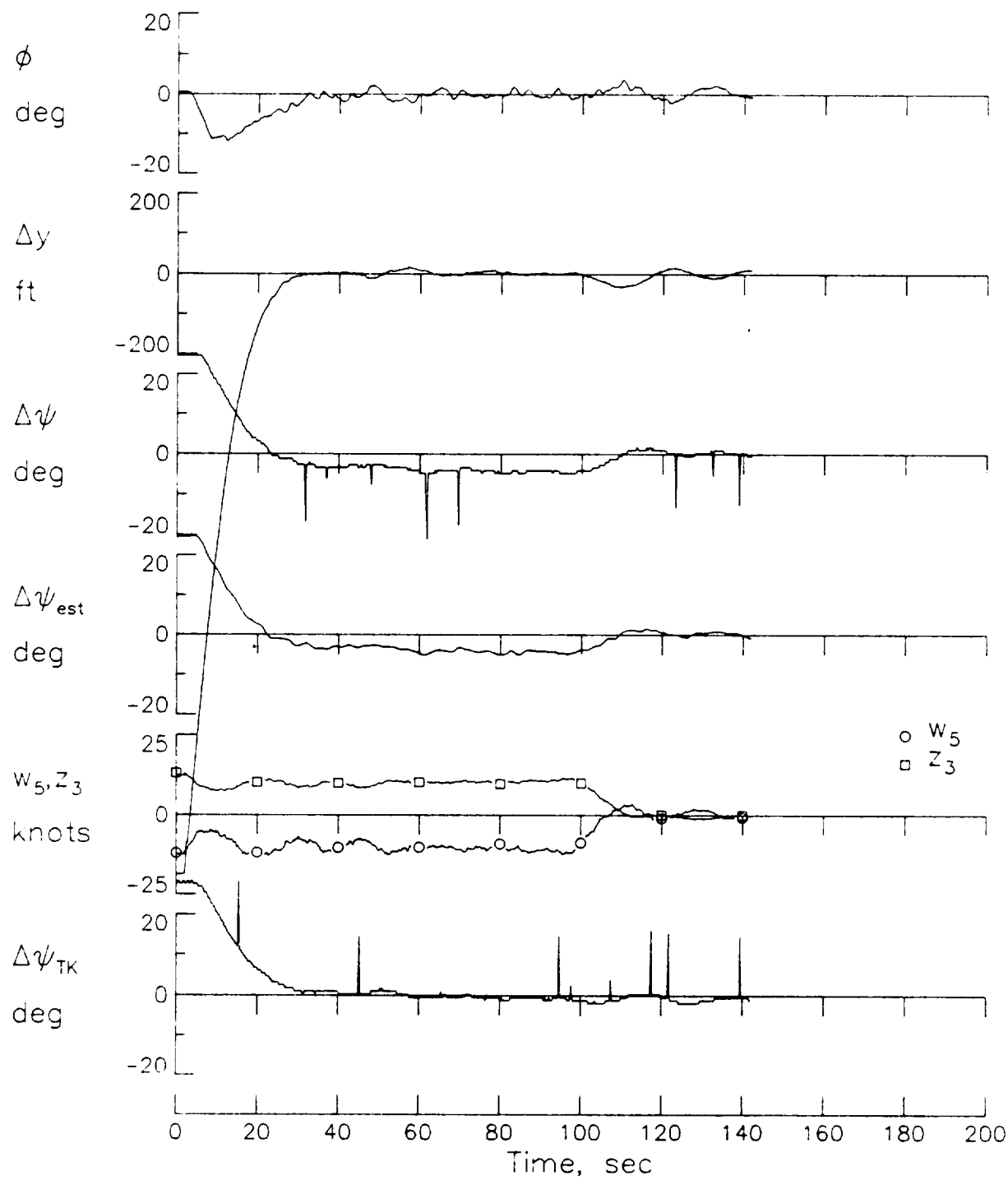


Figure 22. Continued

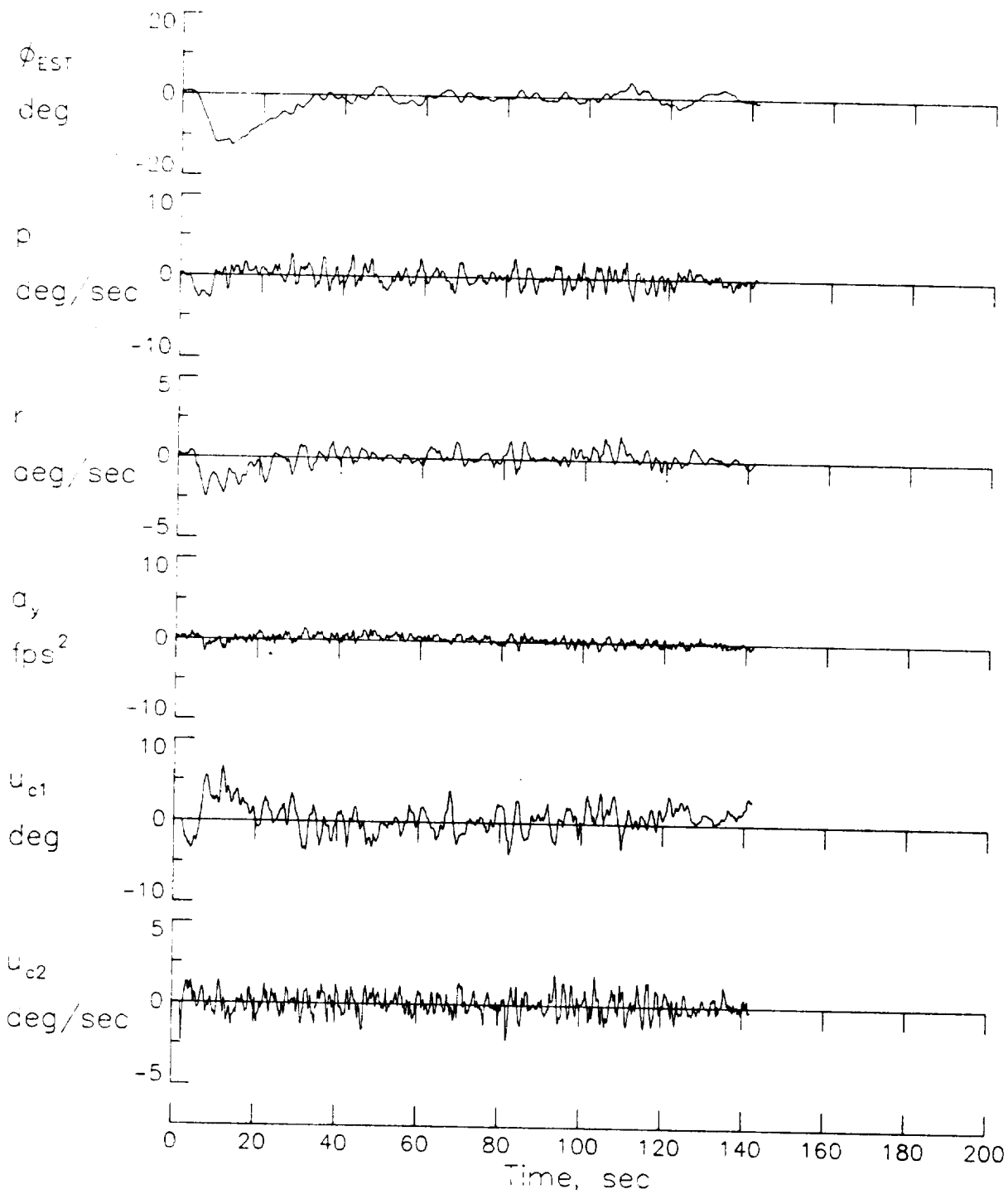


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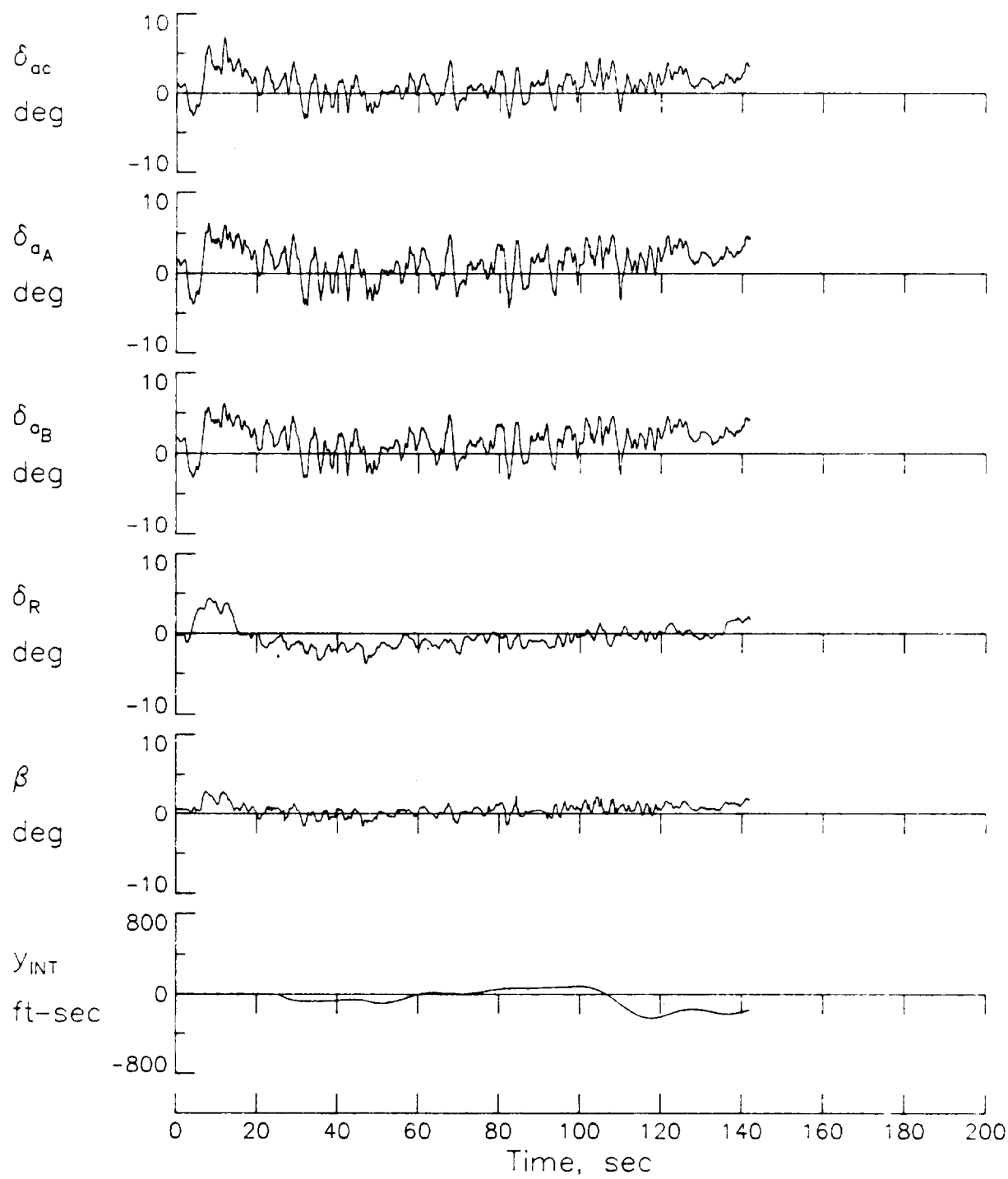


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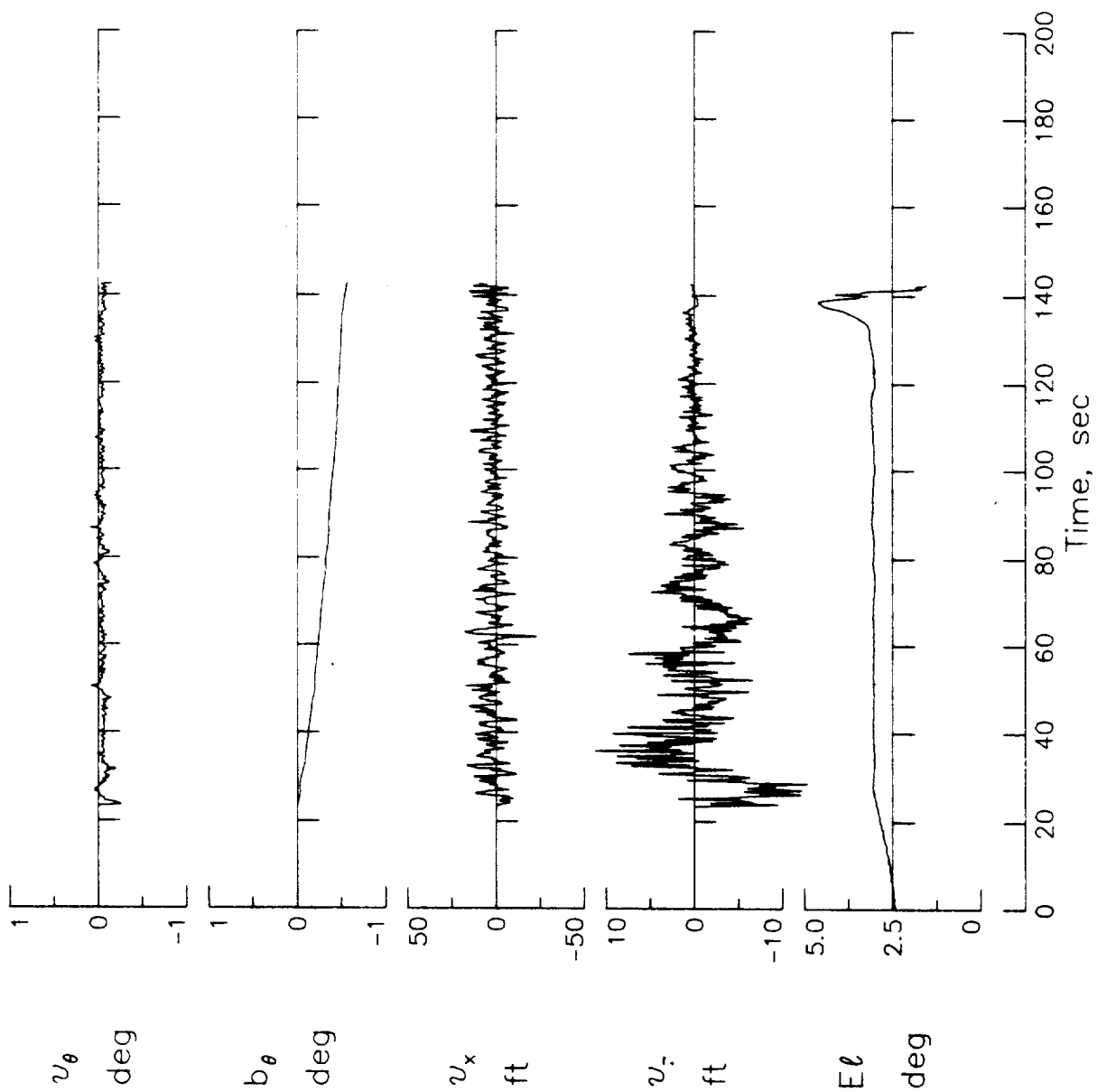


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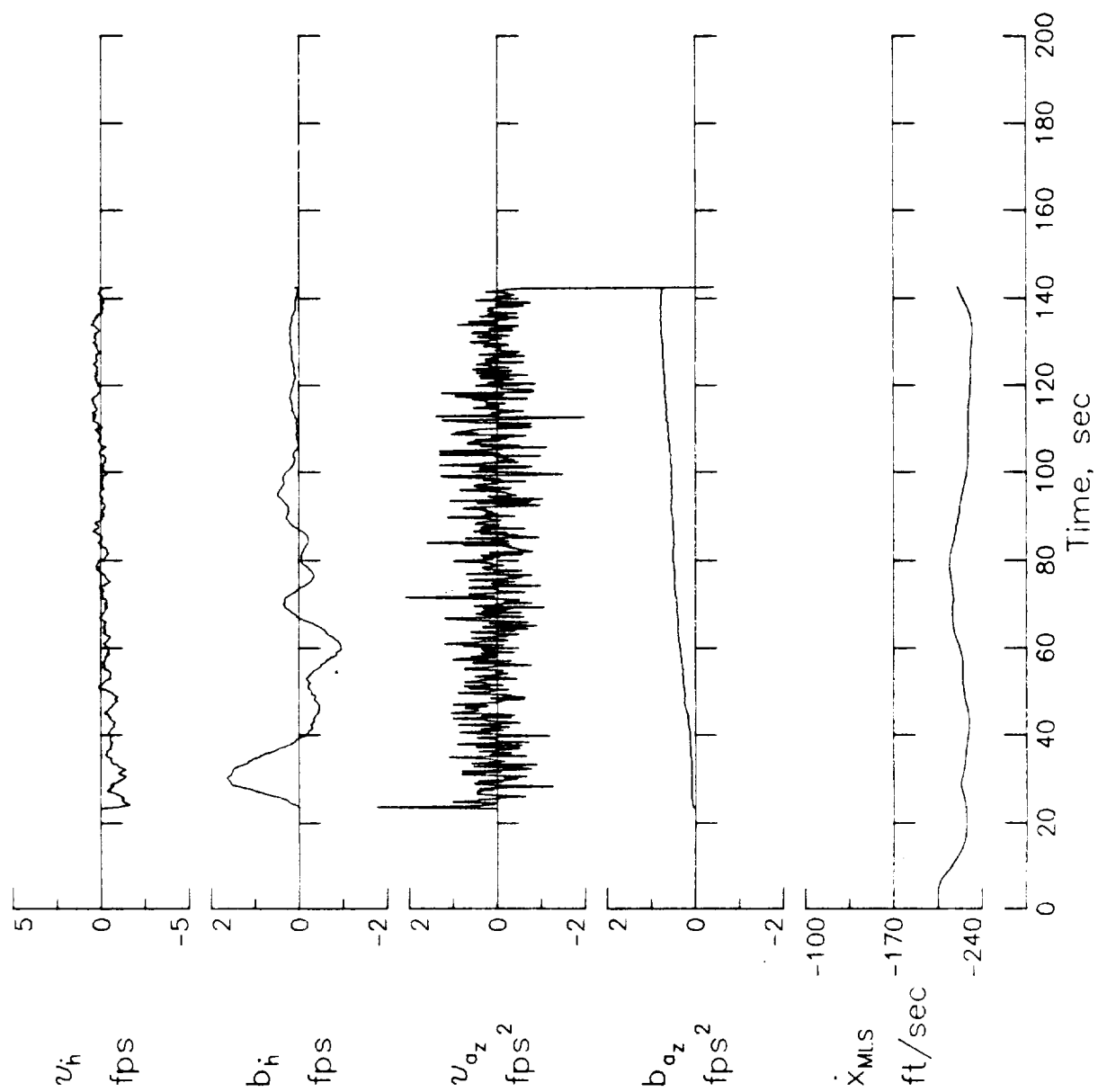


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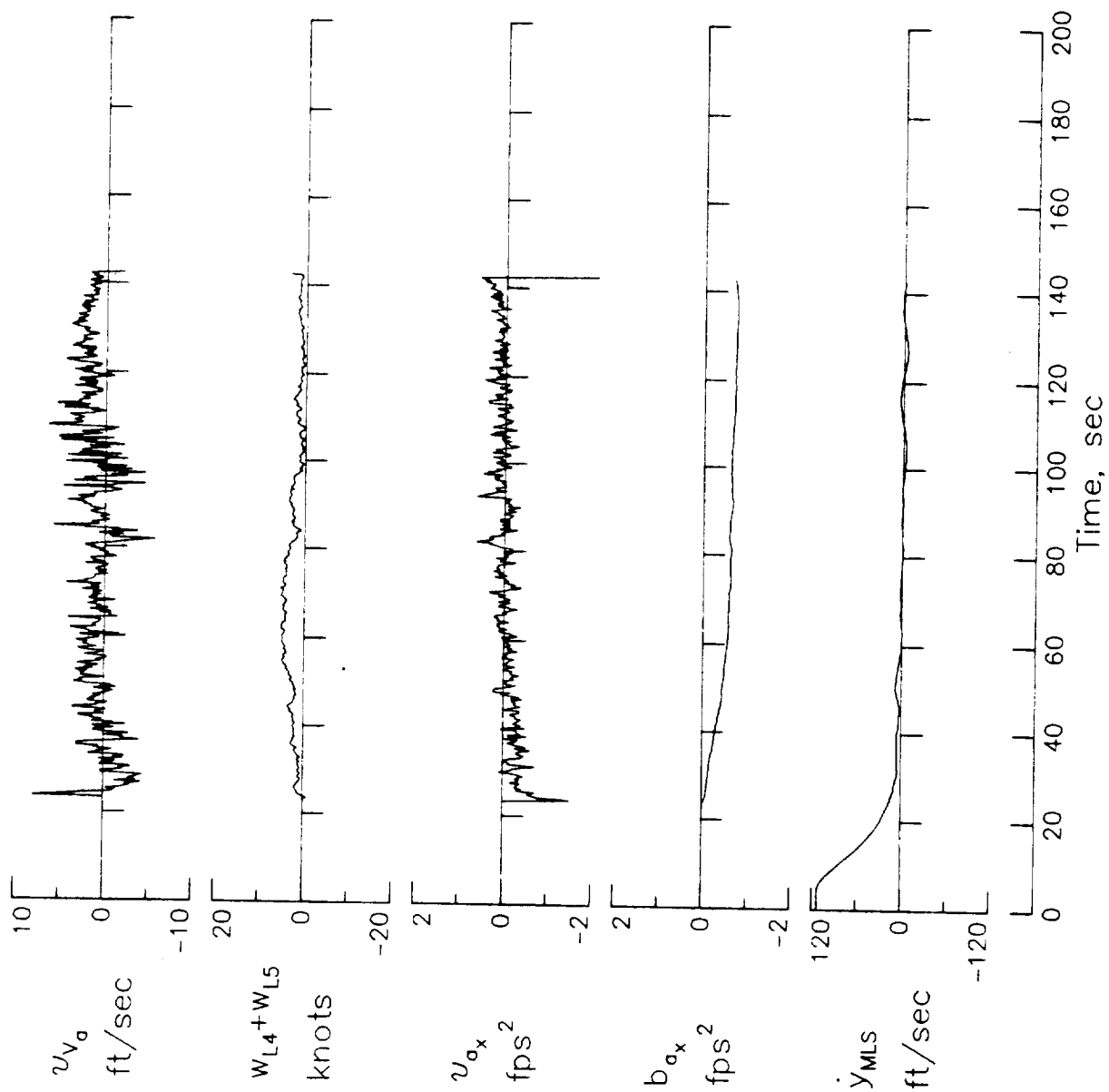


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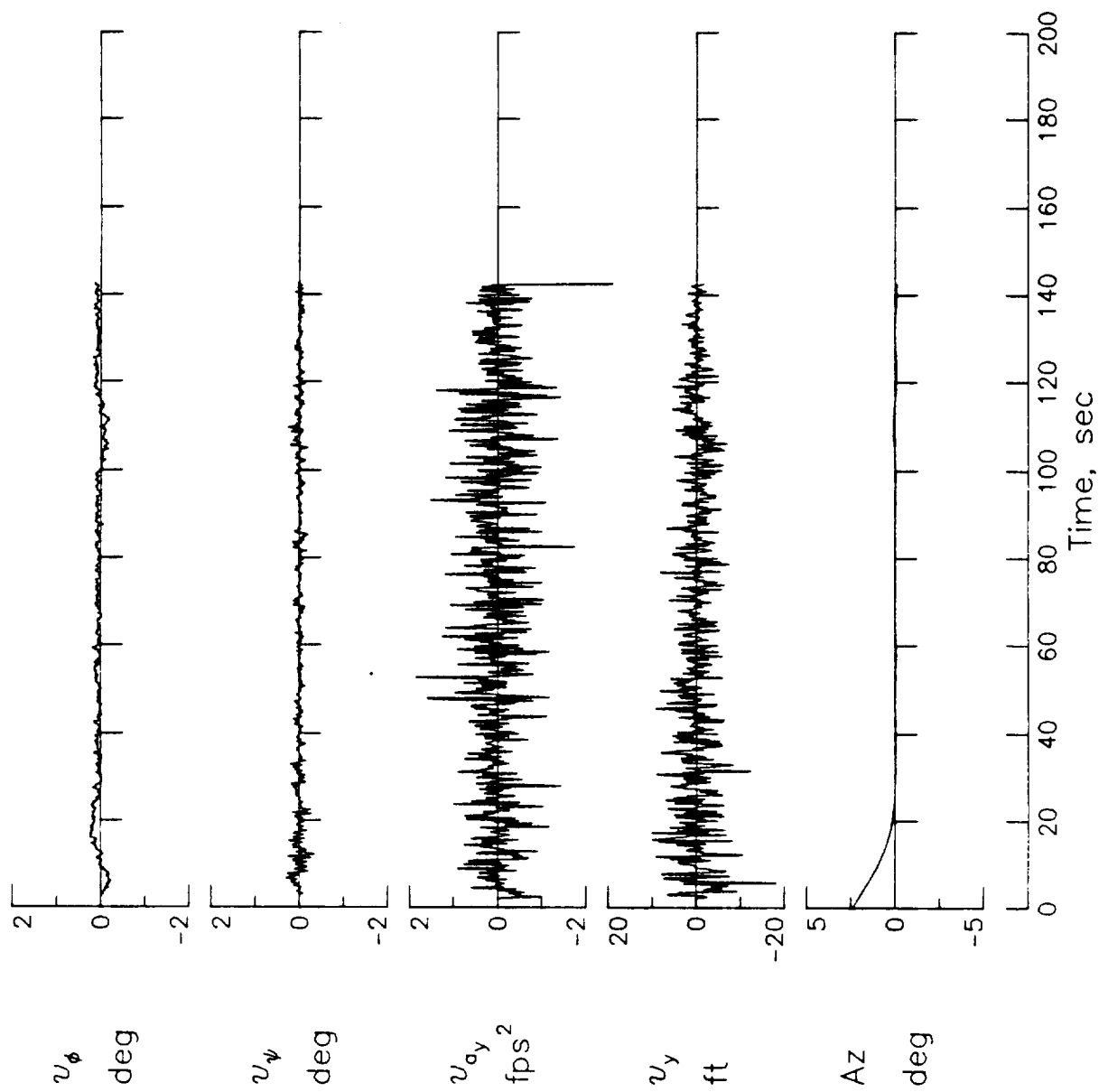


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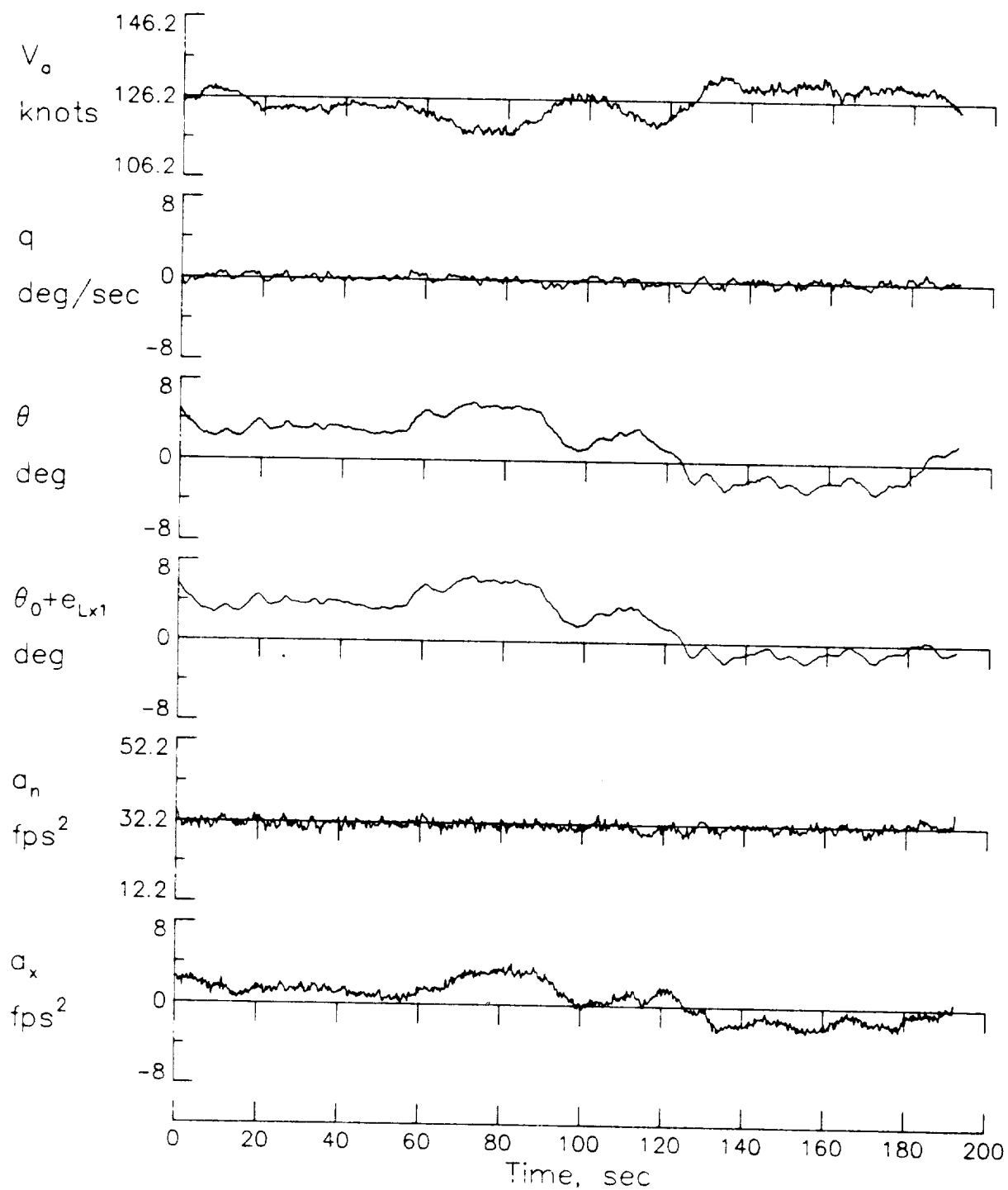


Figure 23. Flight Data for DIALS Flight Test
R361, Run 8

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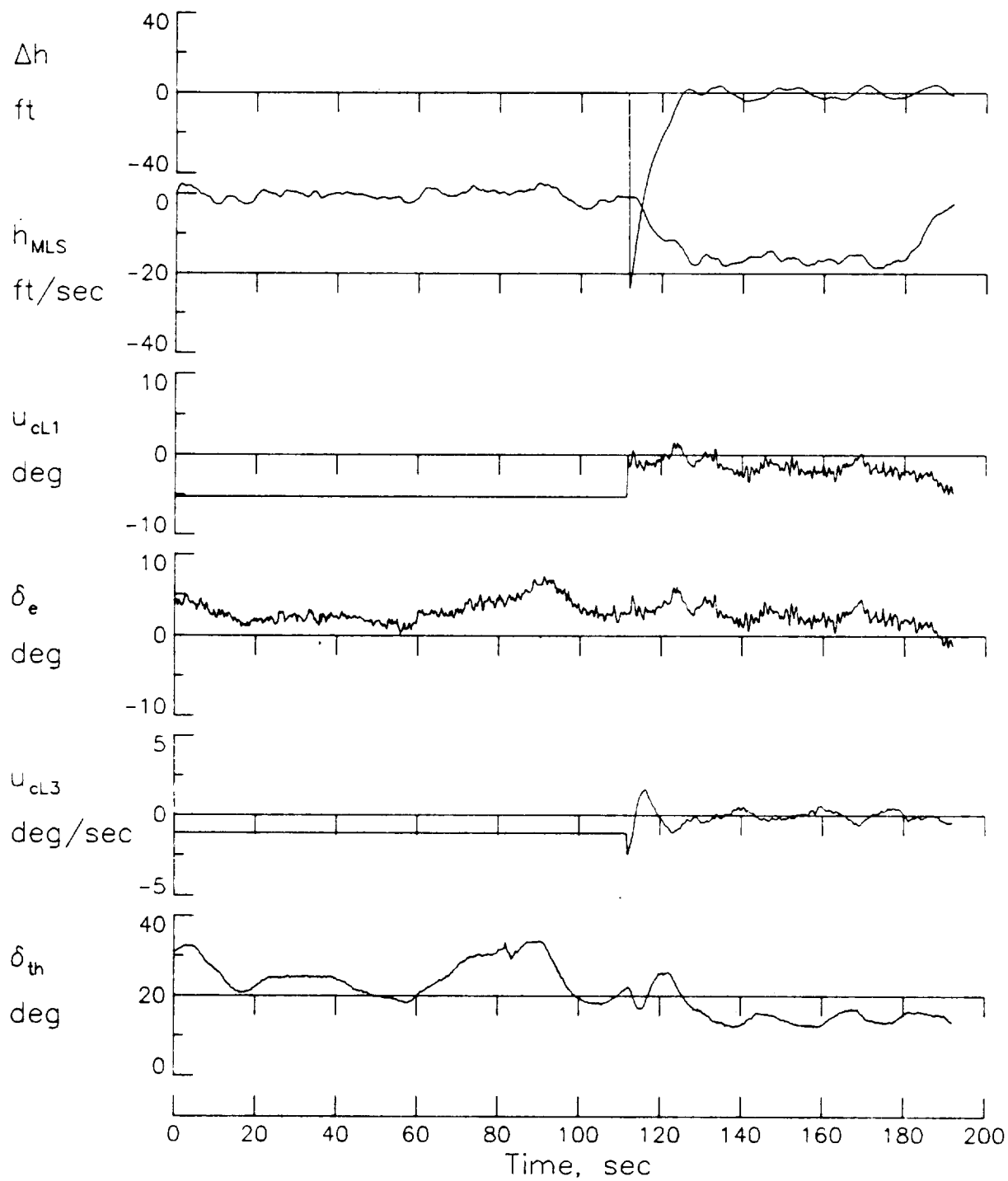


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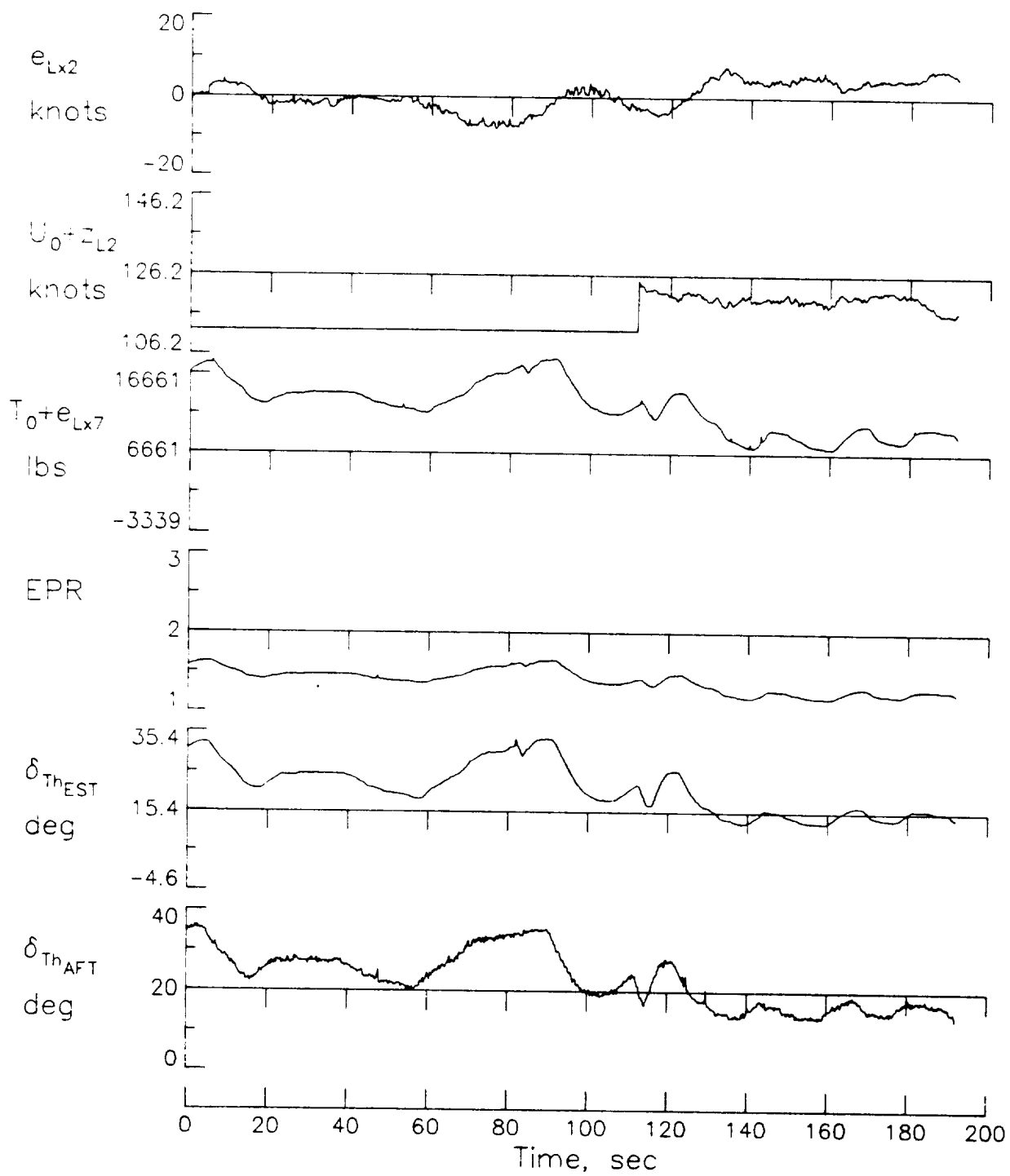


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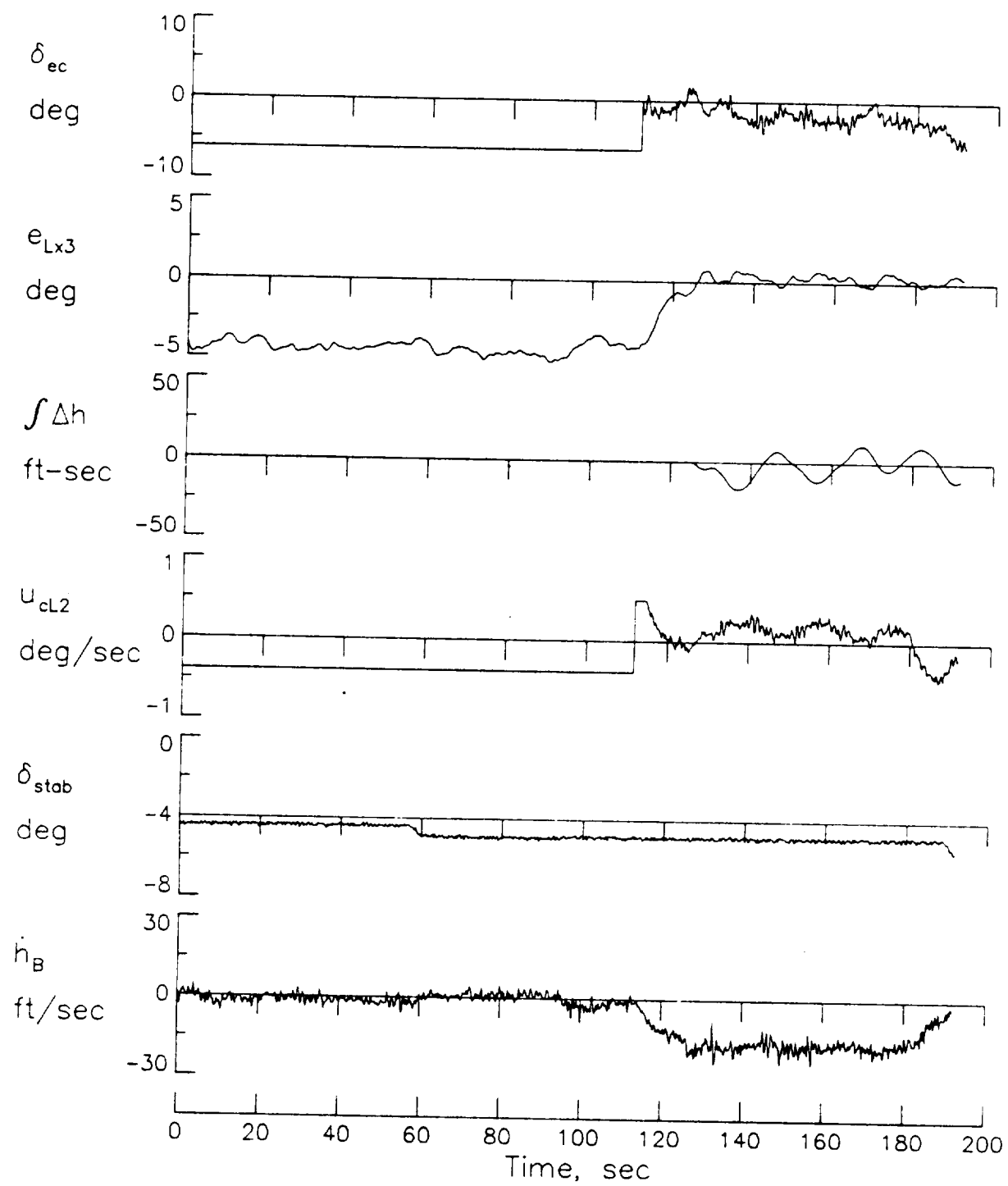


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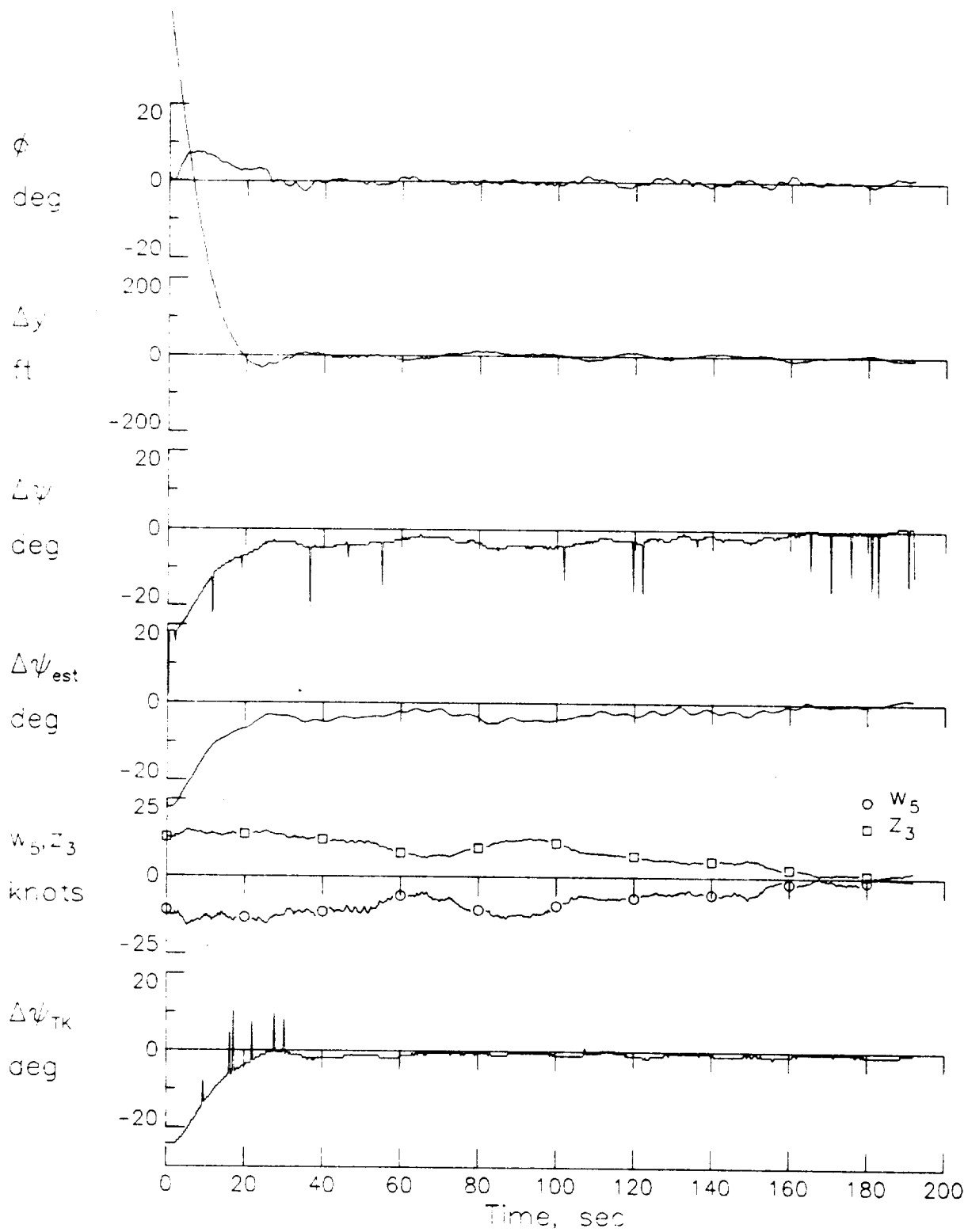


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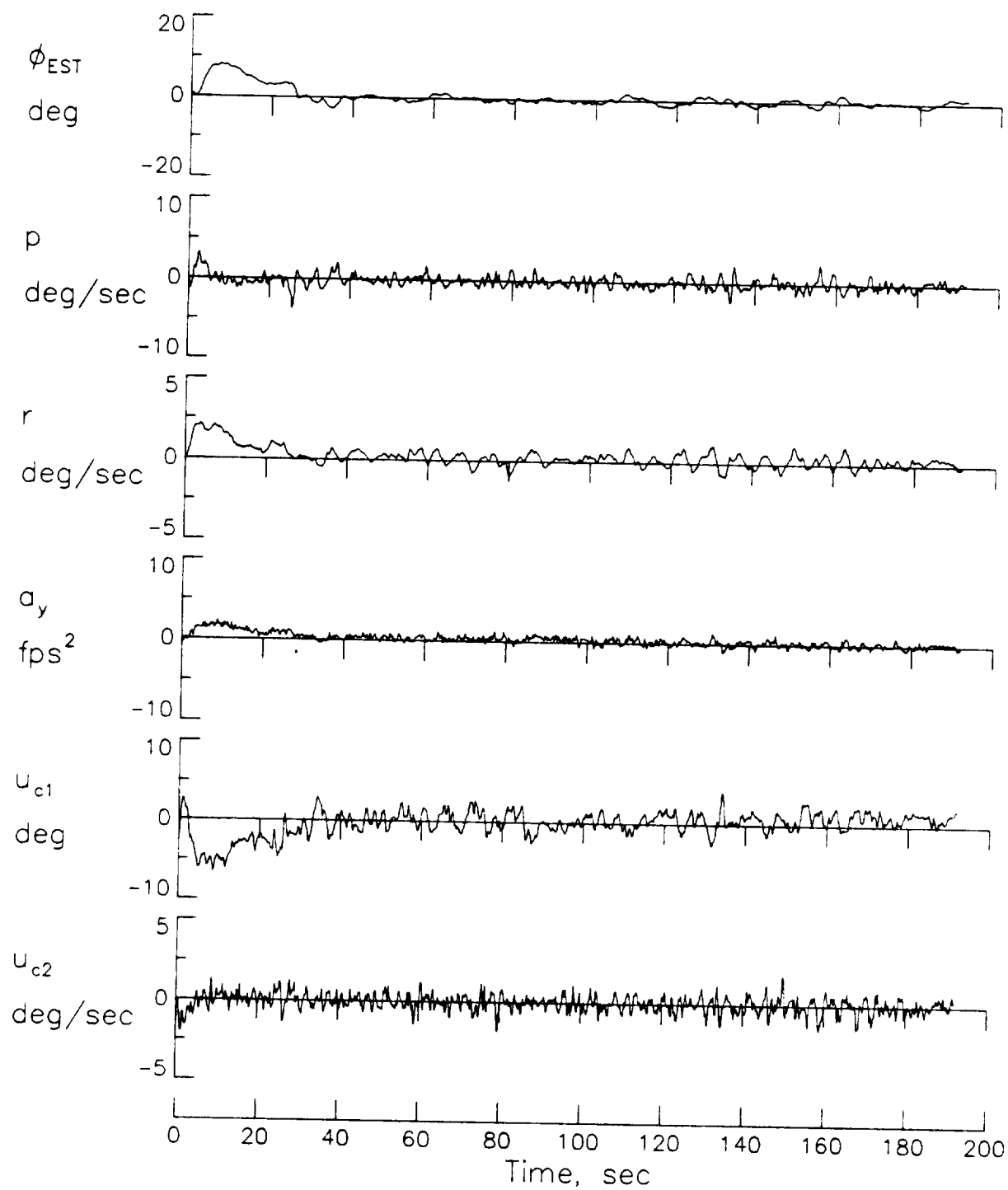


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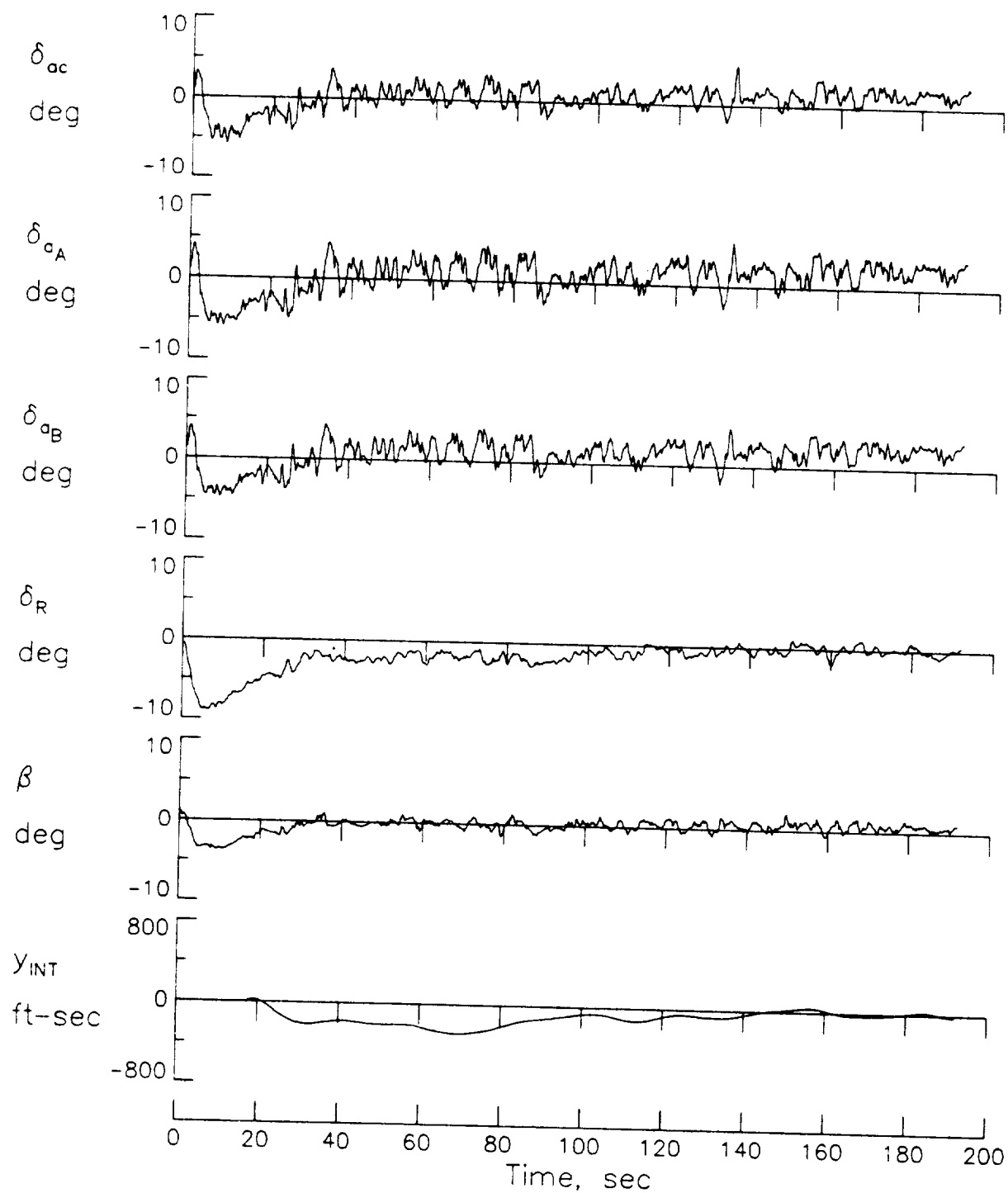


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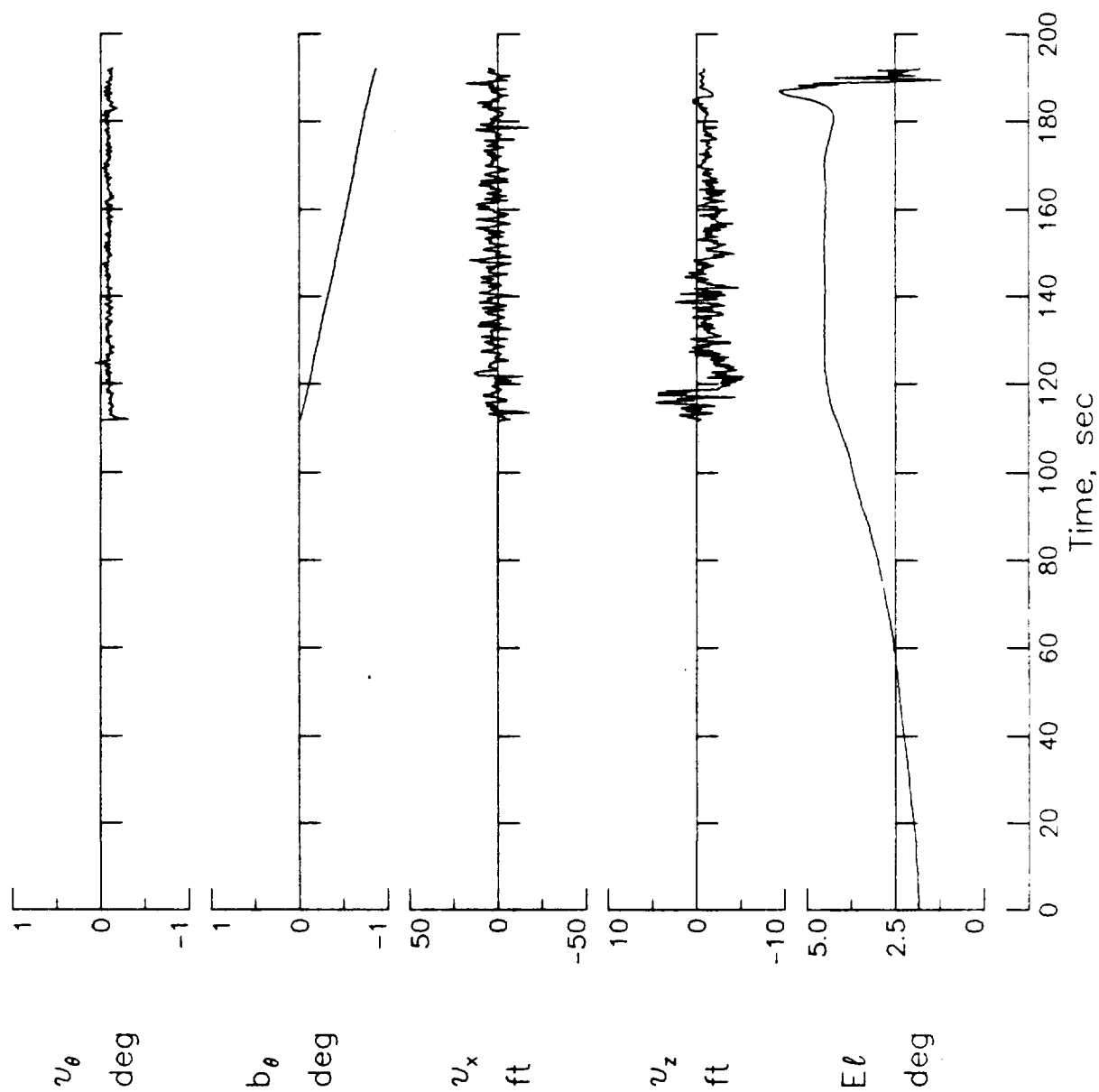


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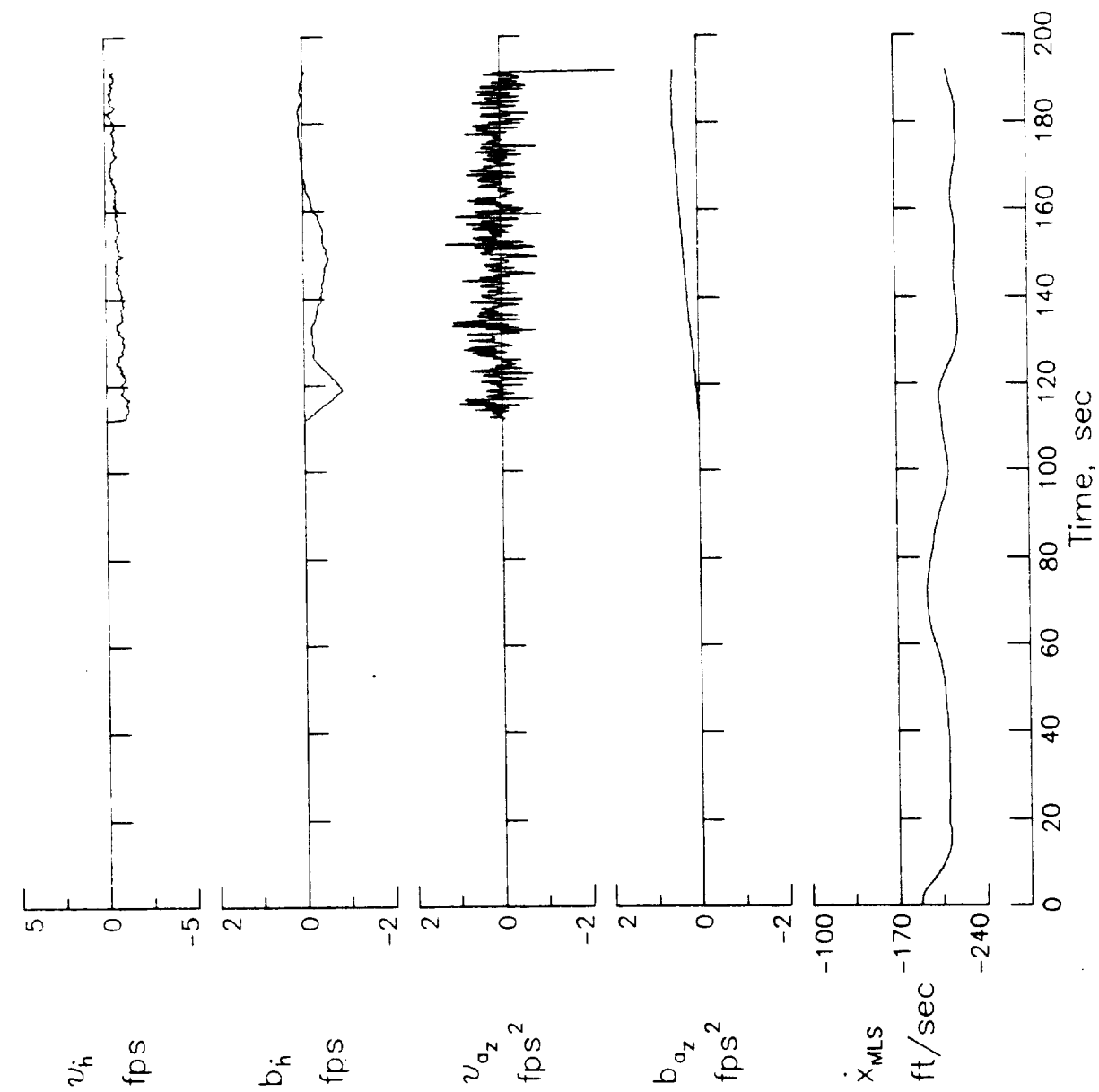


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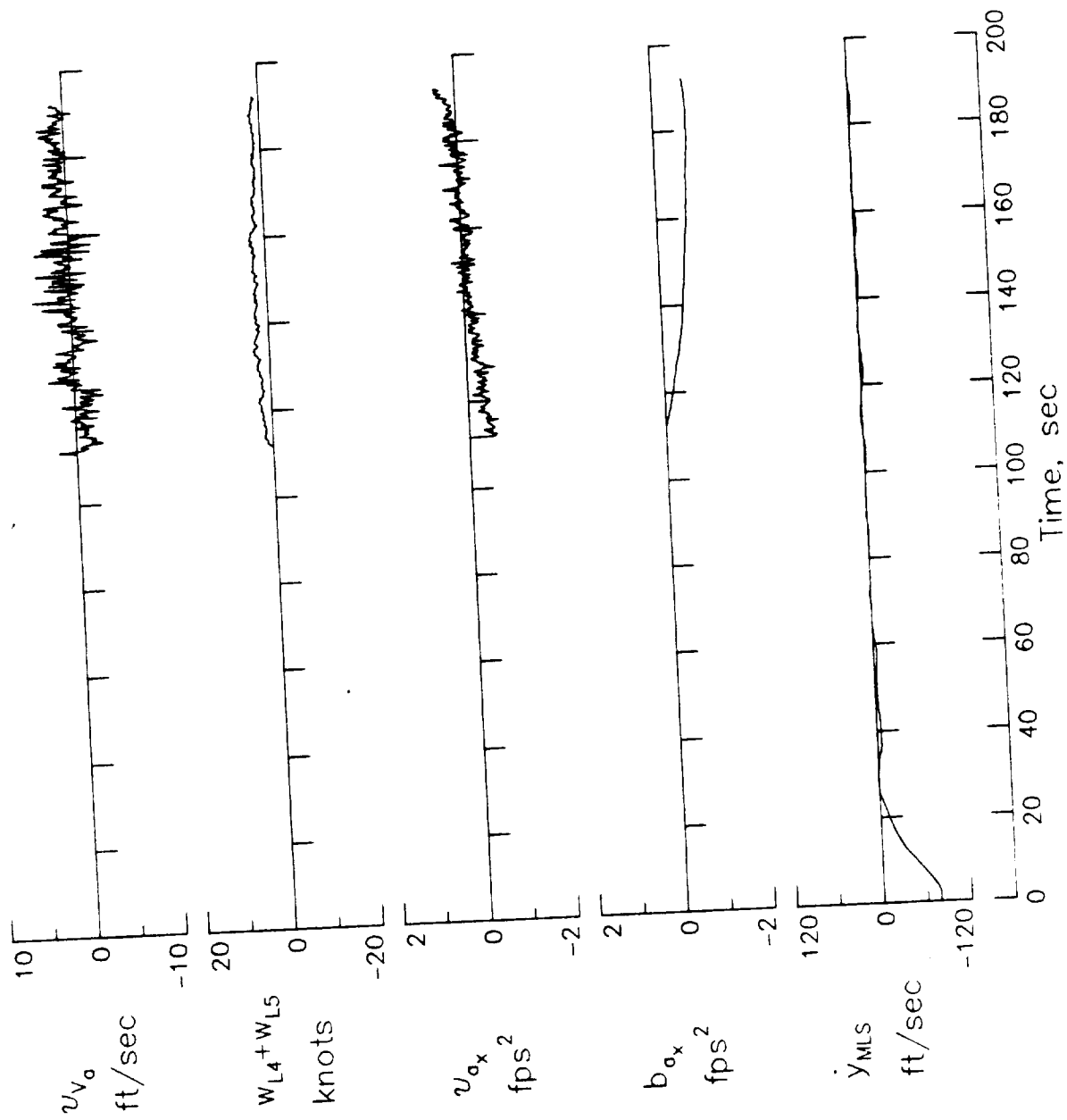


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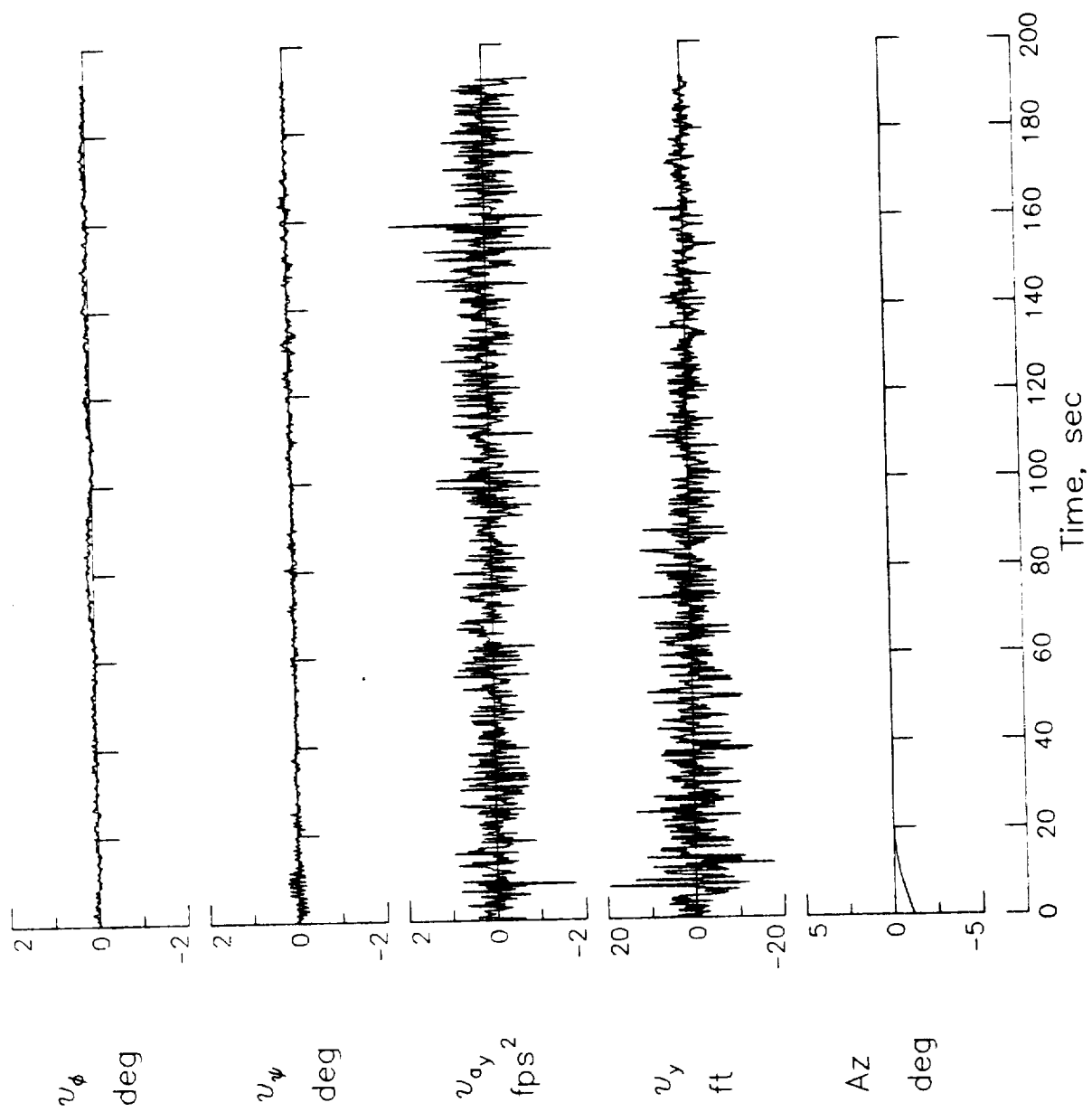


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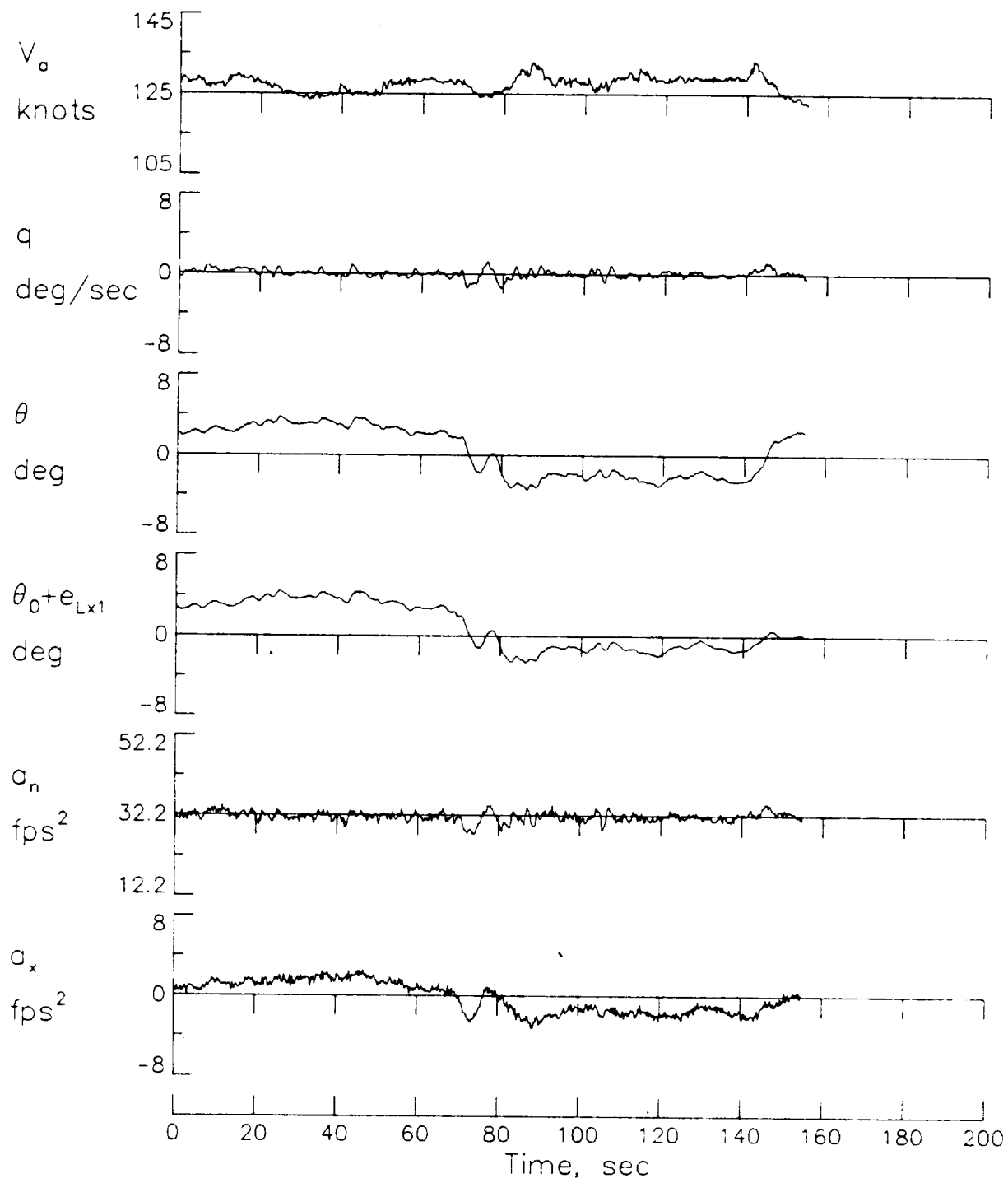


Figure 24. Flight Data for DIALS Flight Test R361, Run 9

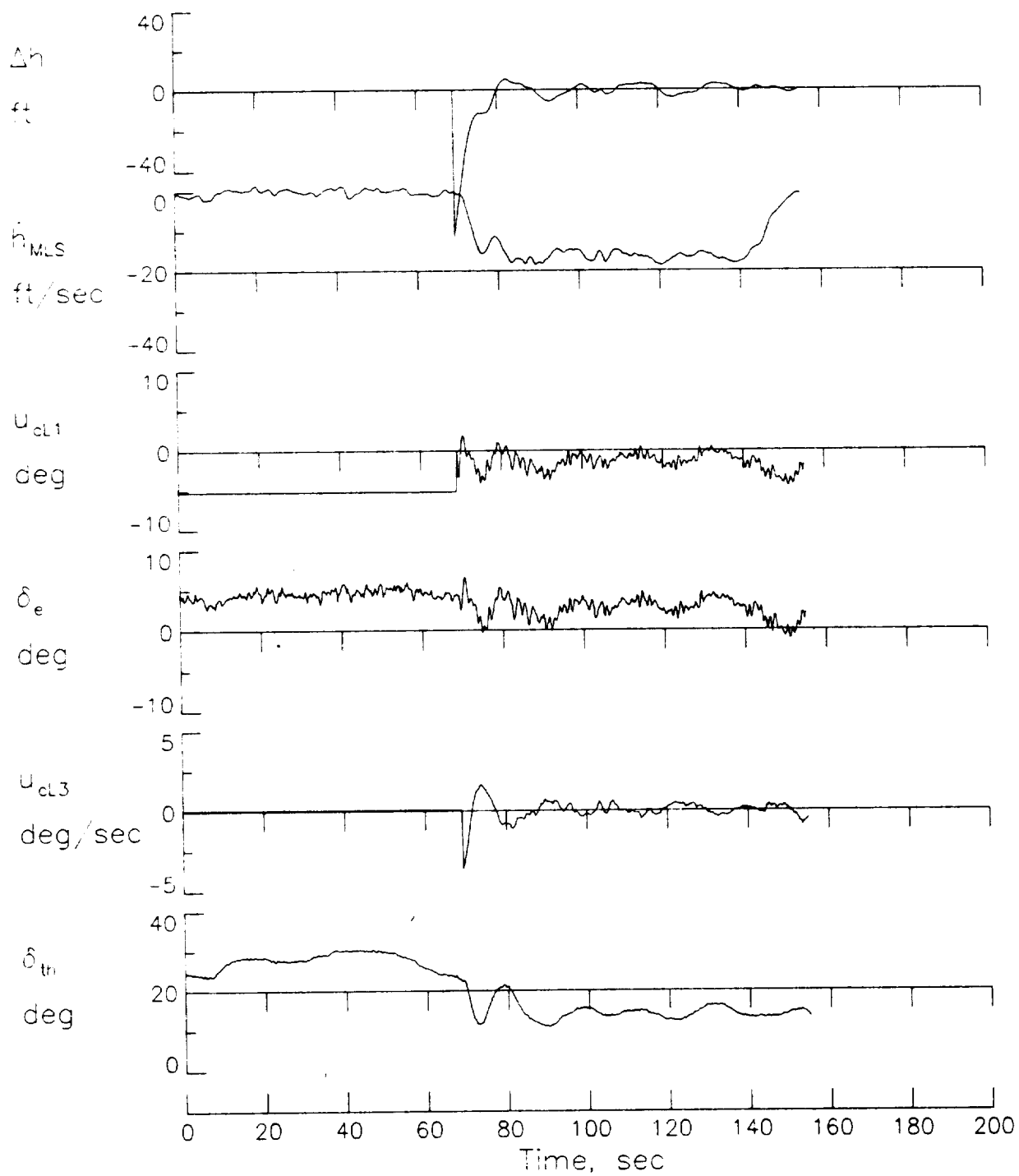


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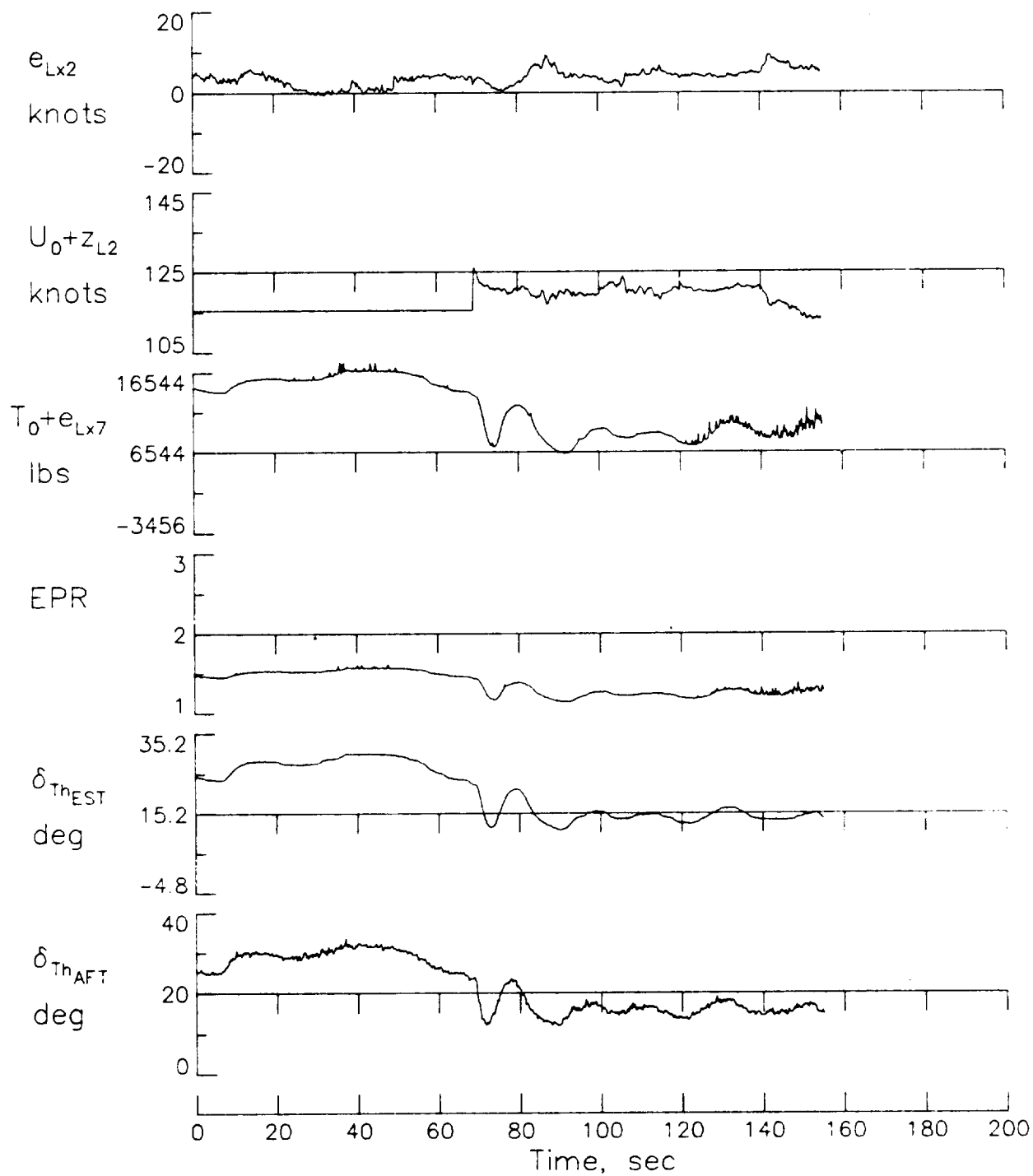


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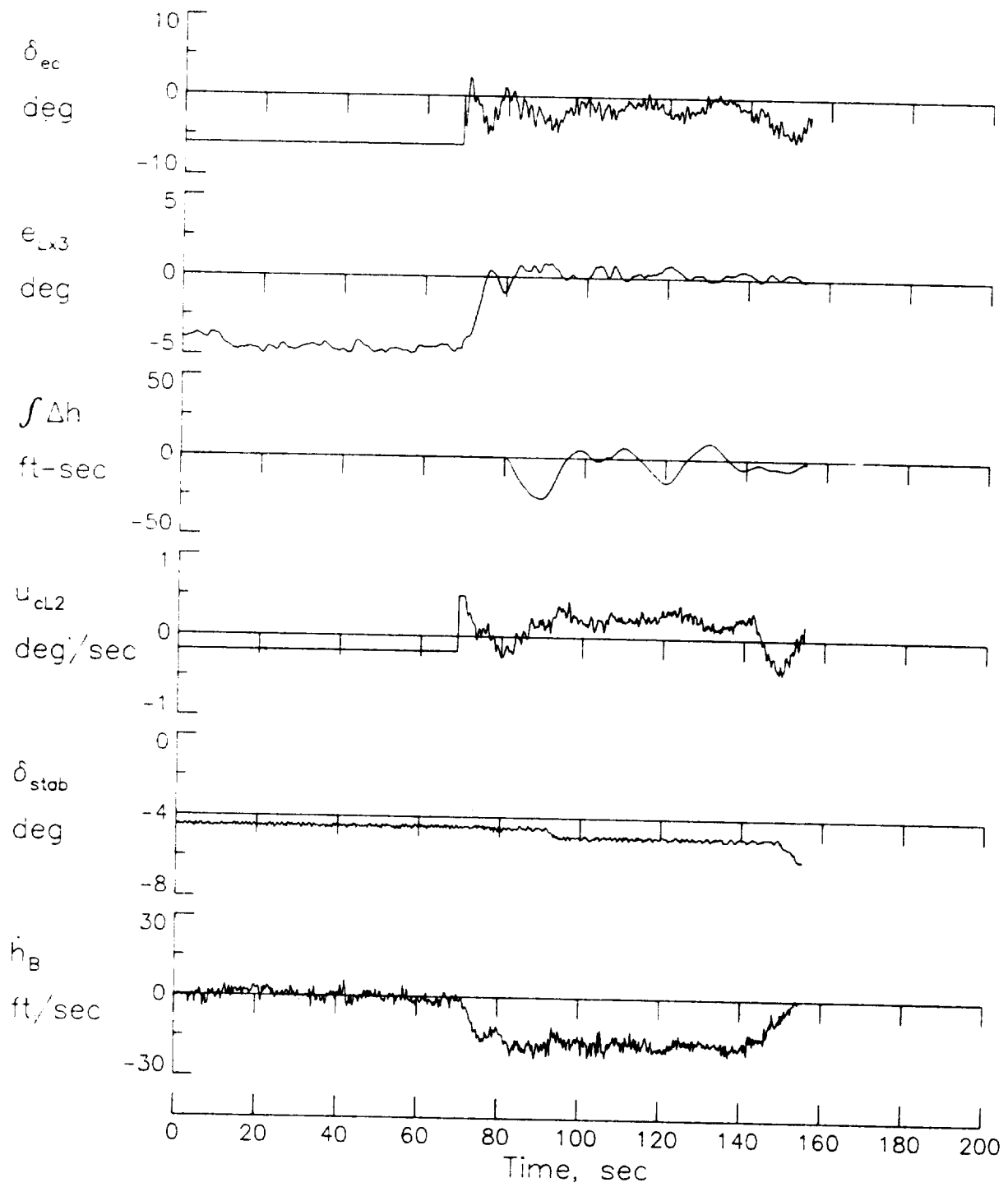


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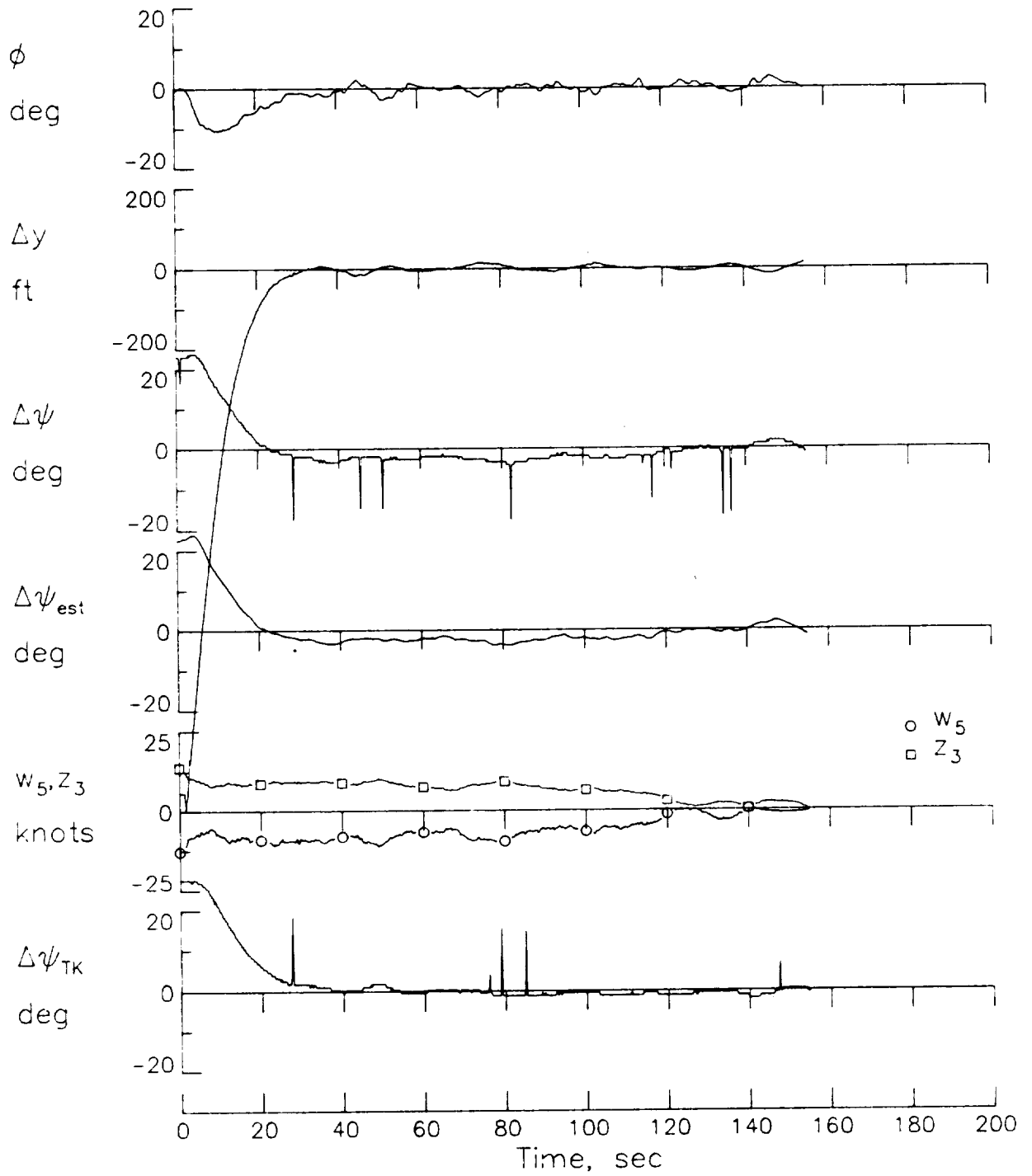


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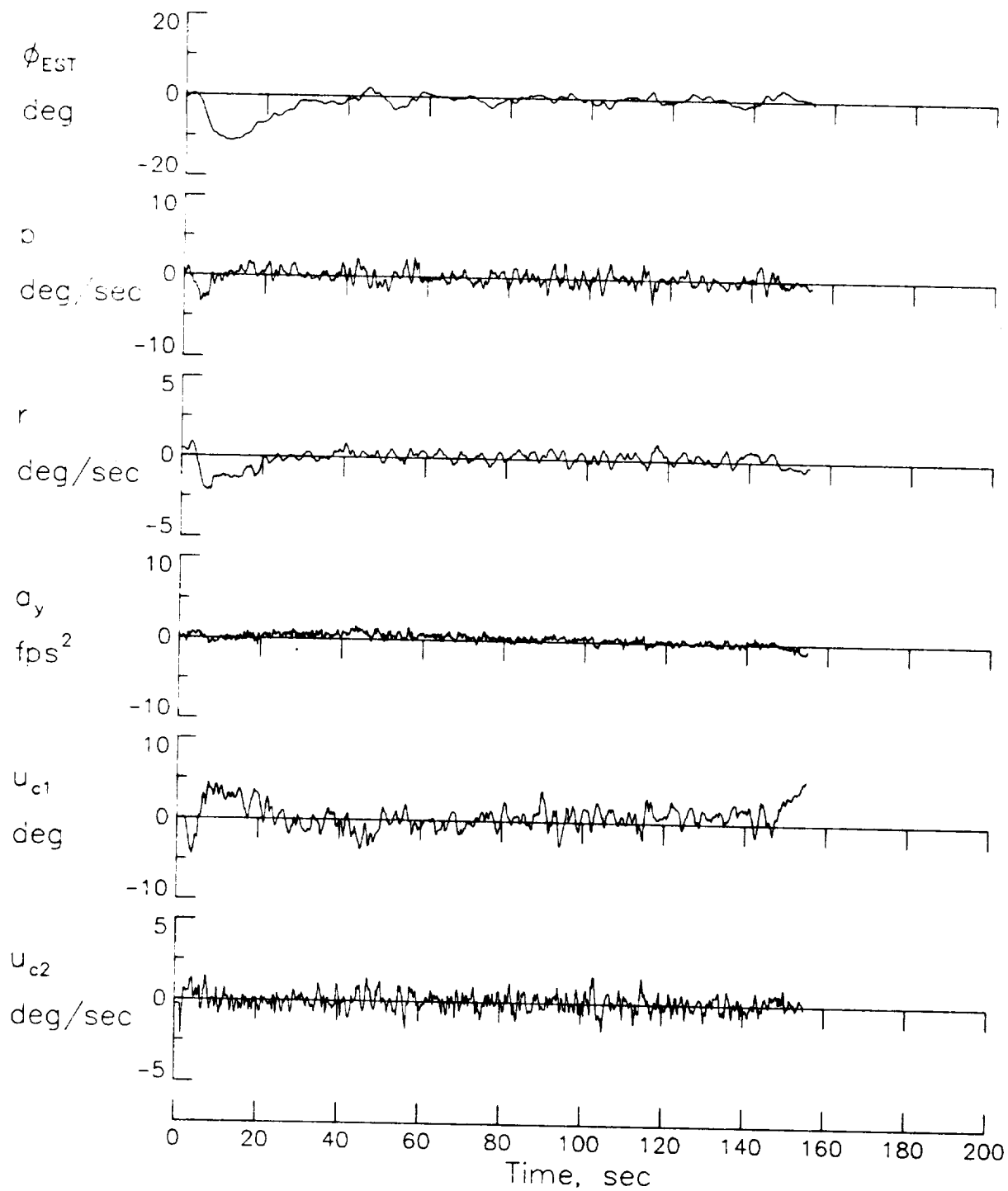


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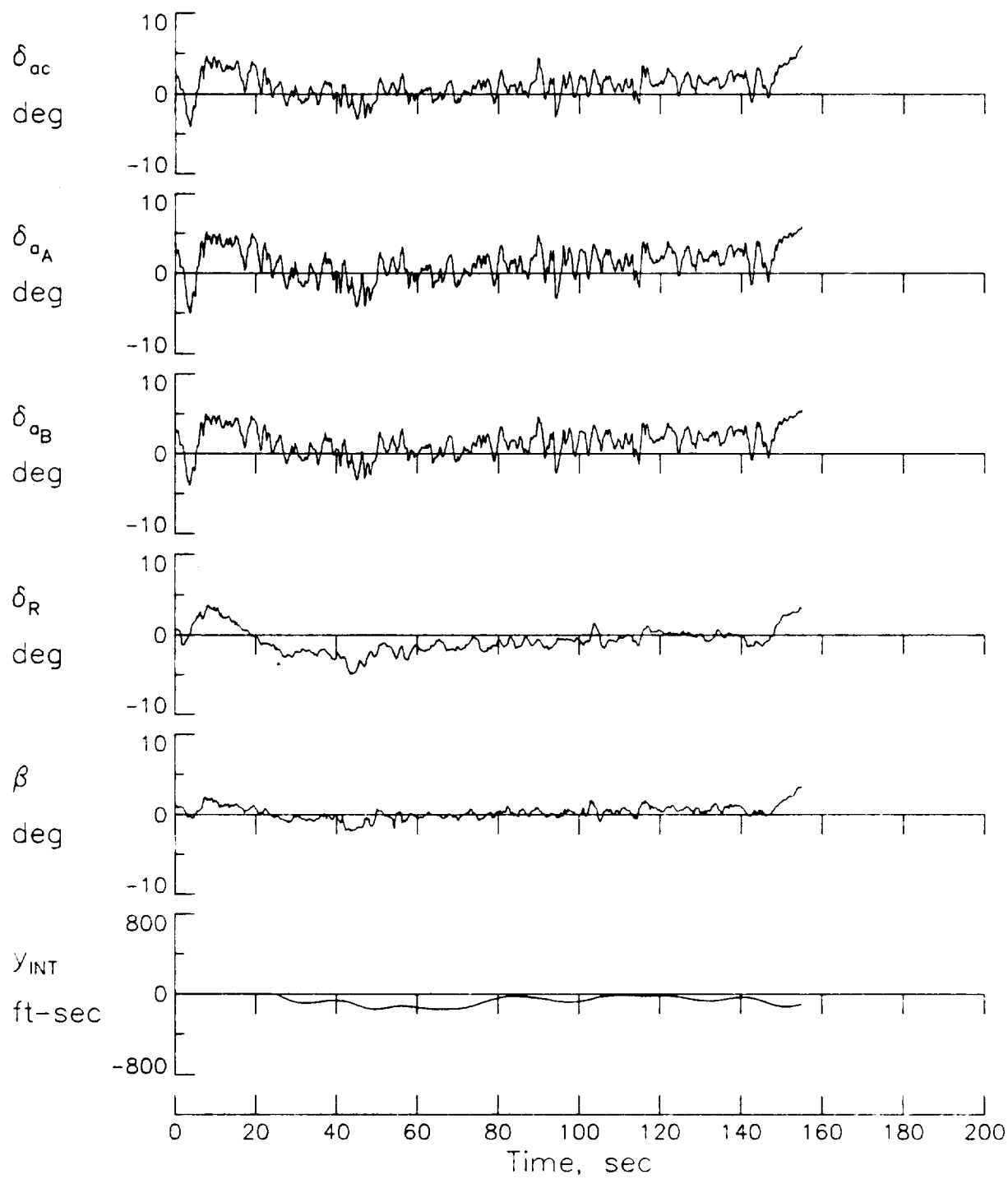


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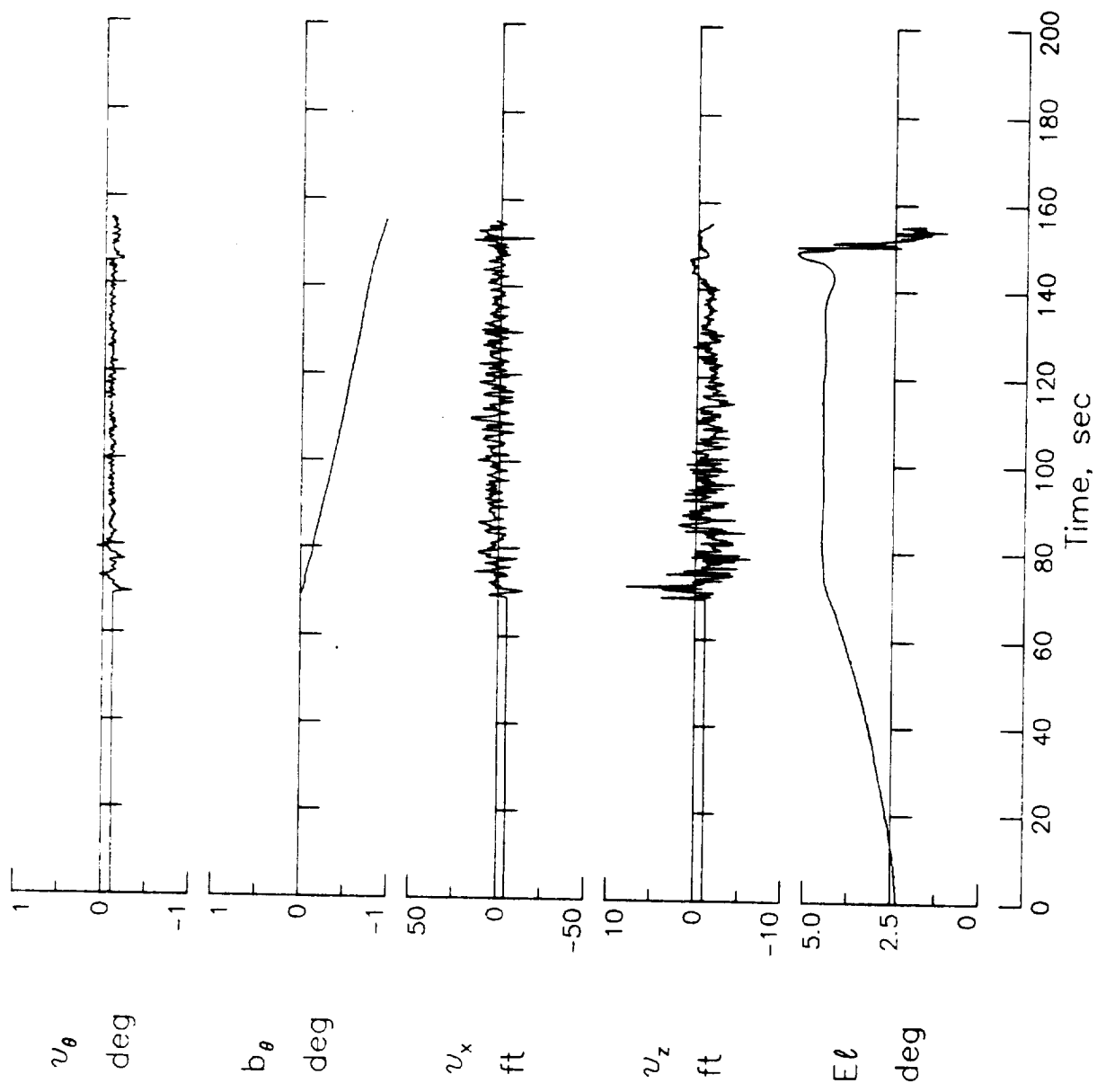


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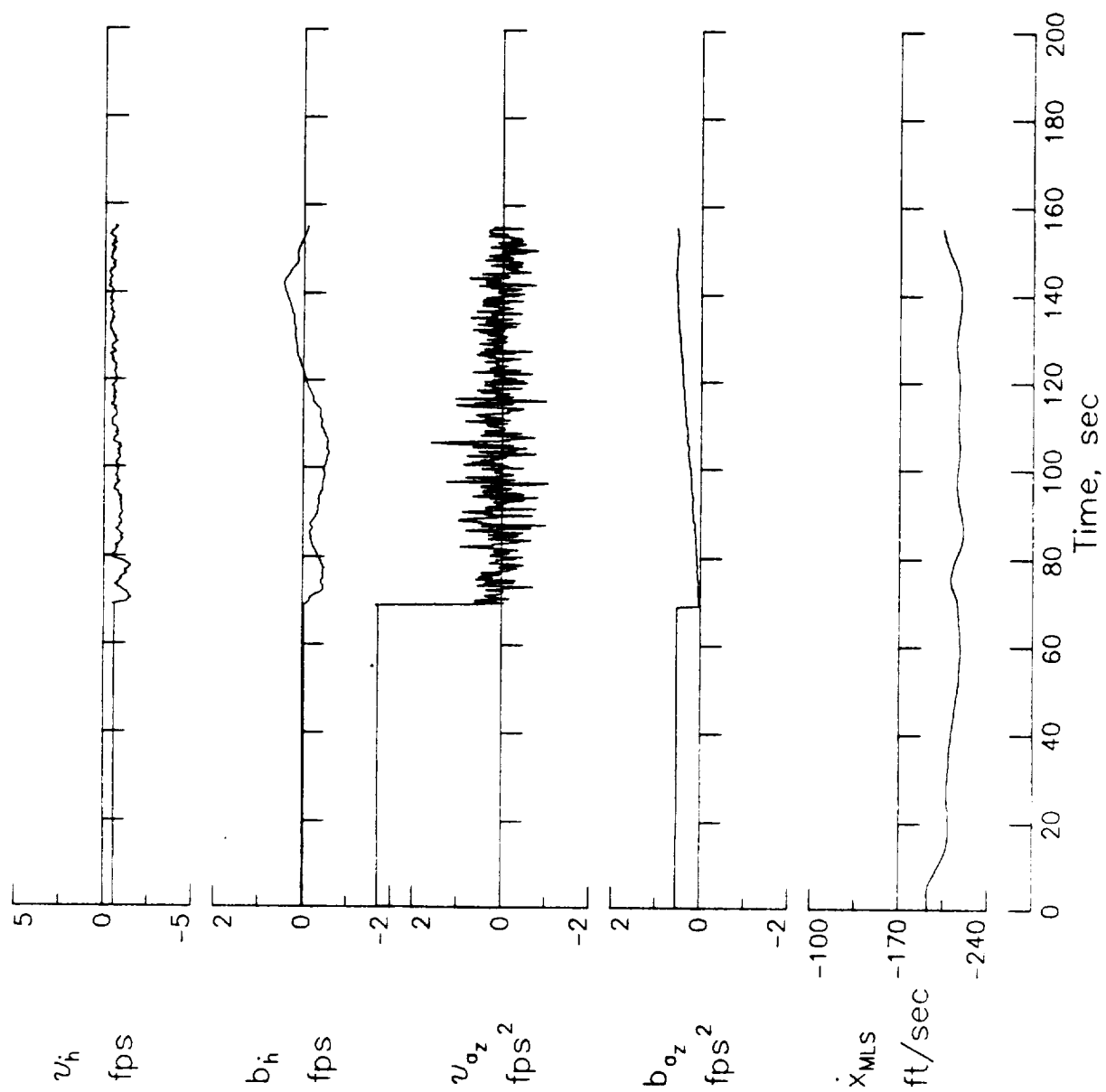


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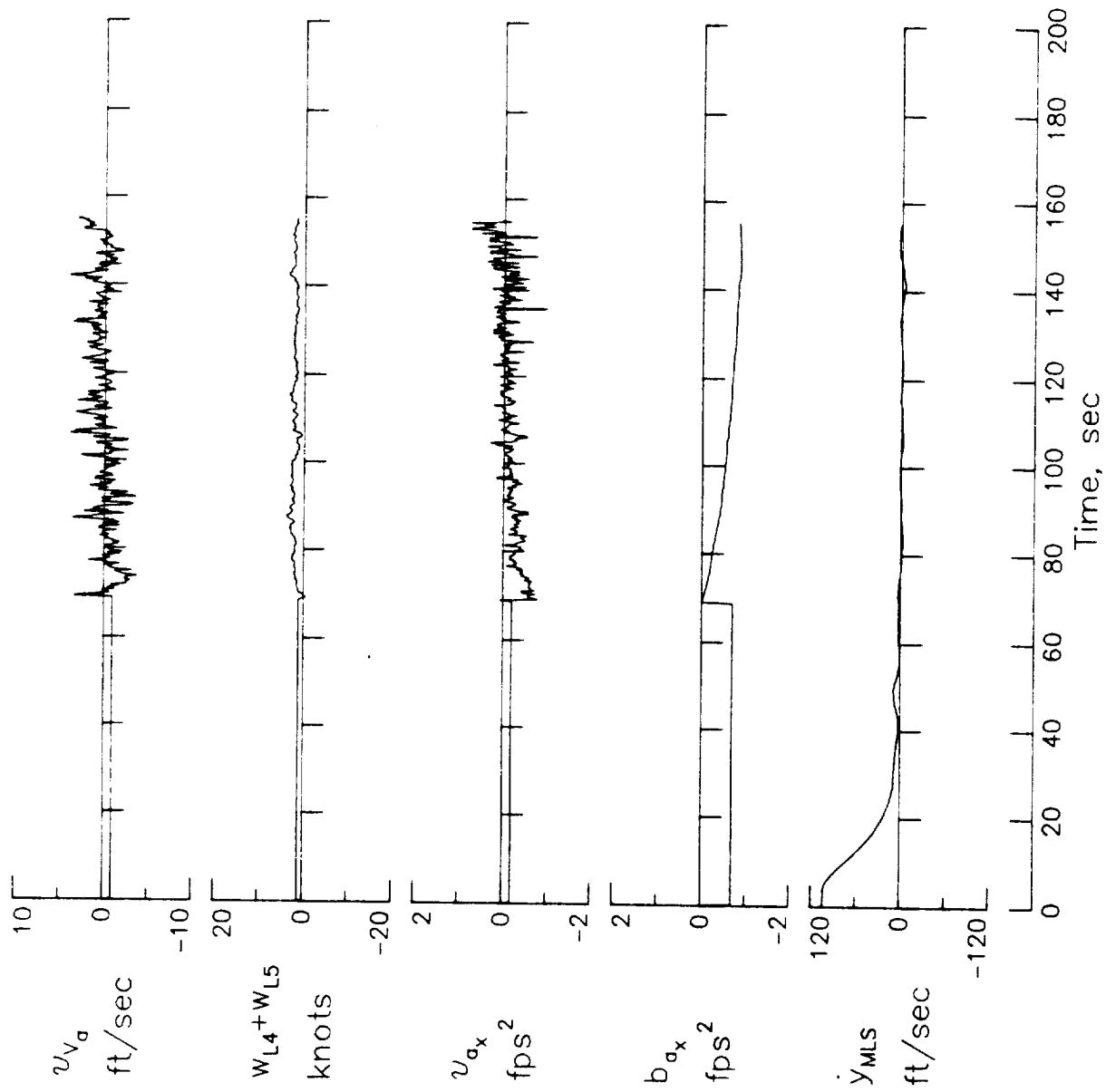


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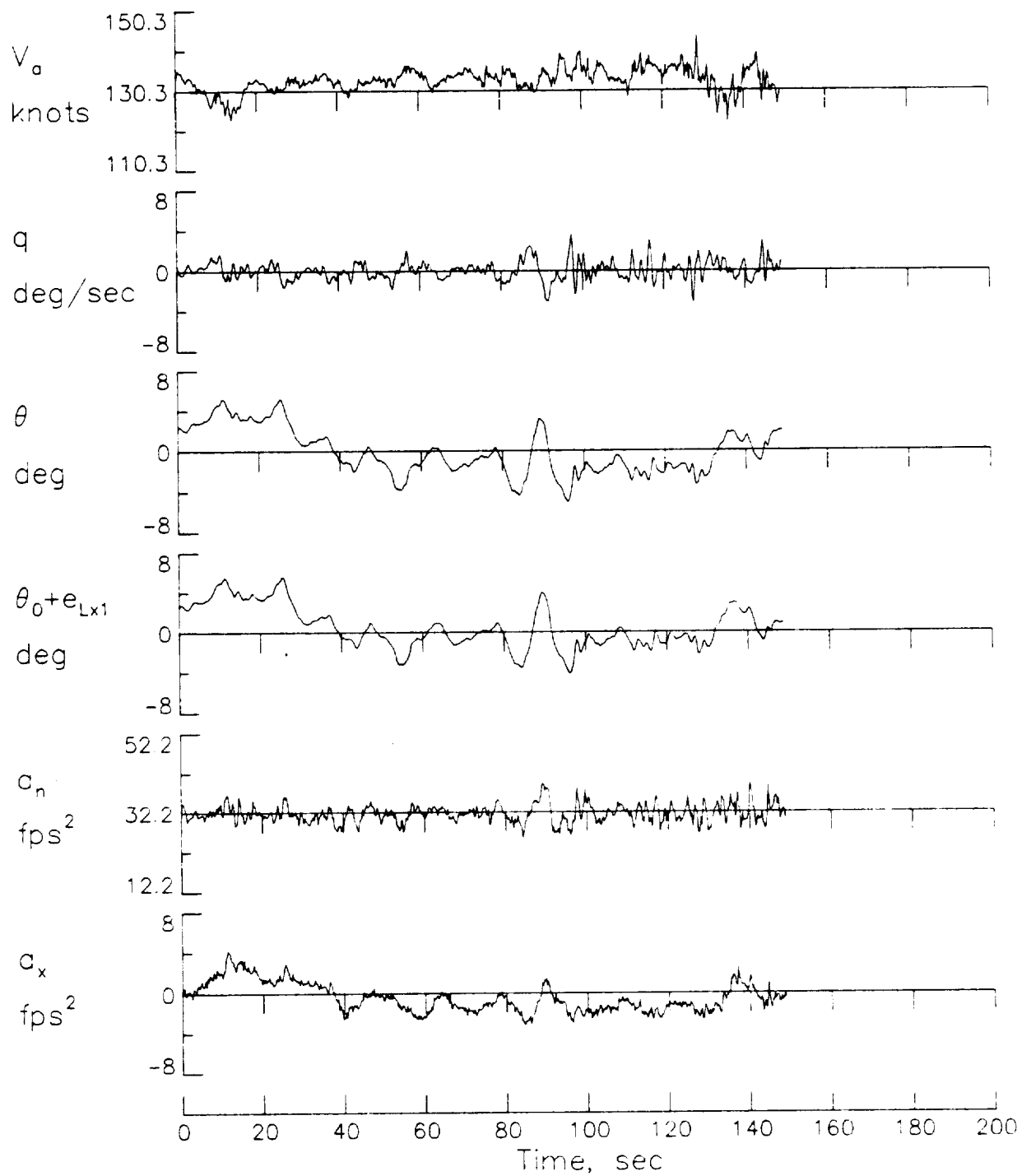


Figure 25. Flight Data for DIALS Flight Test
R364, Run 4

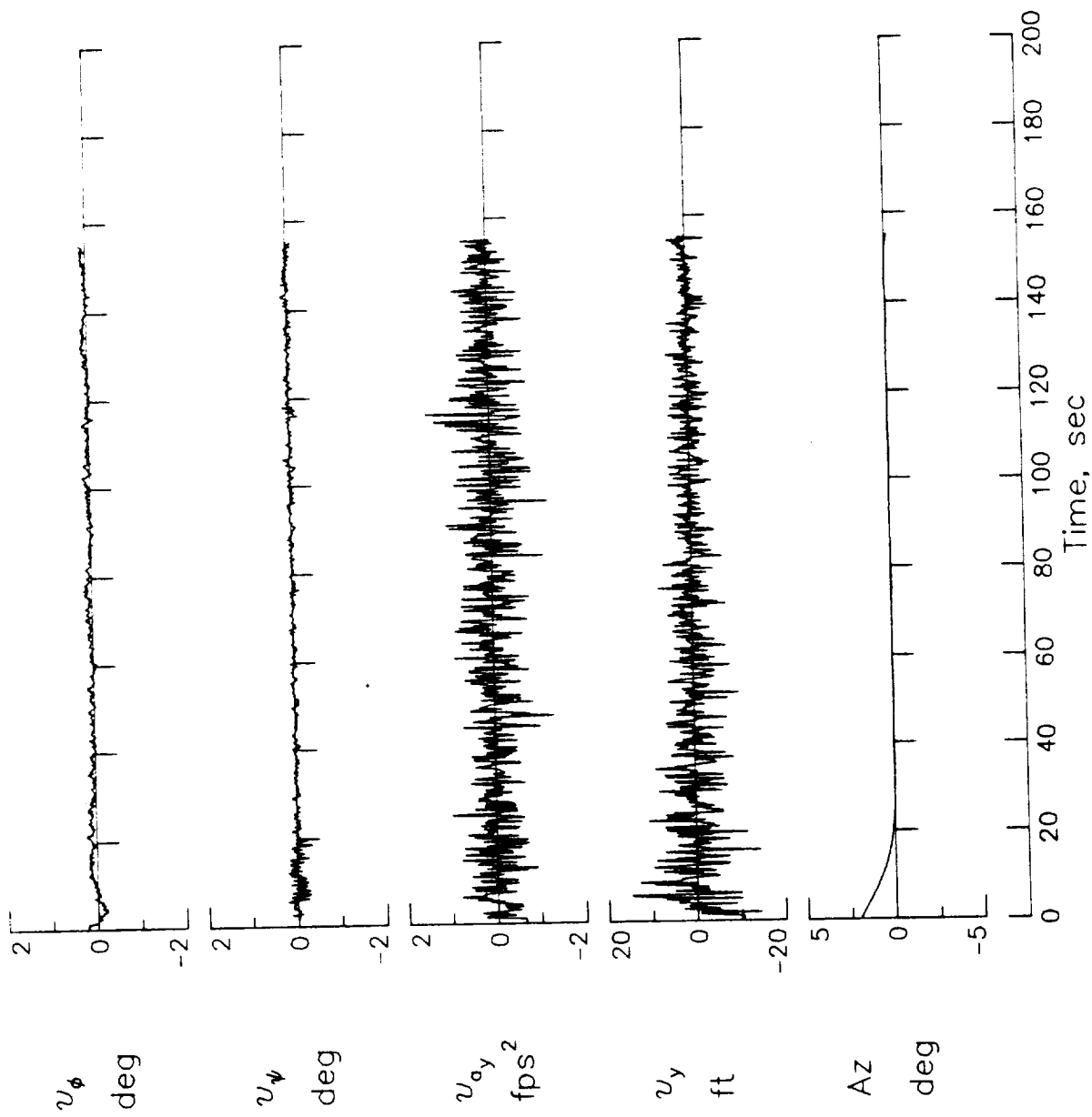


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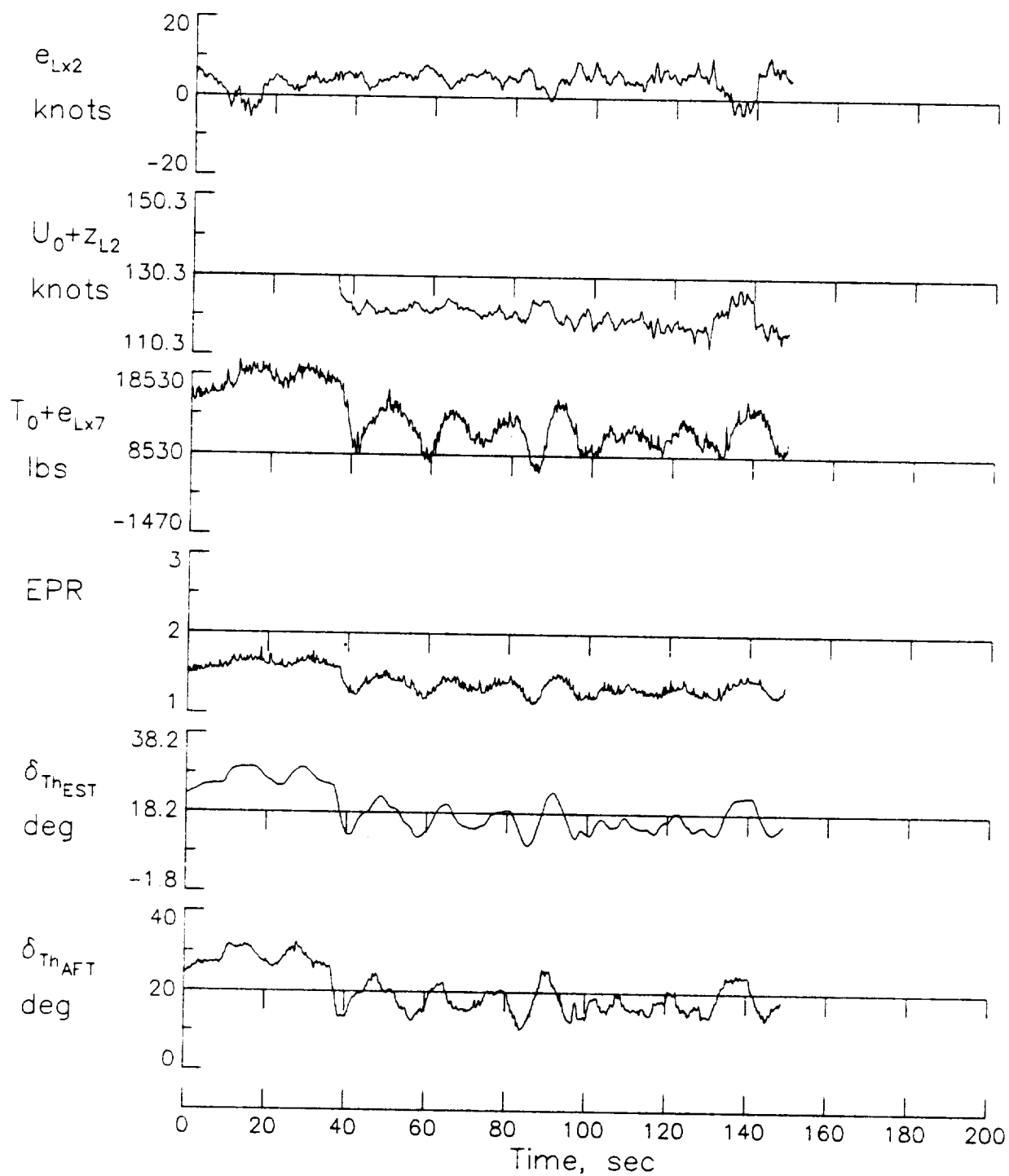


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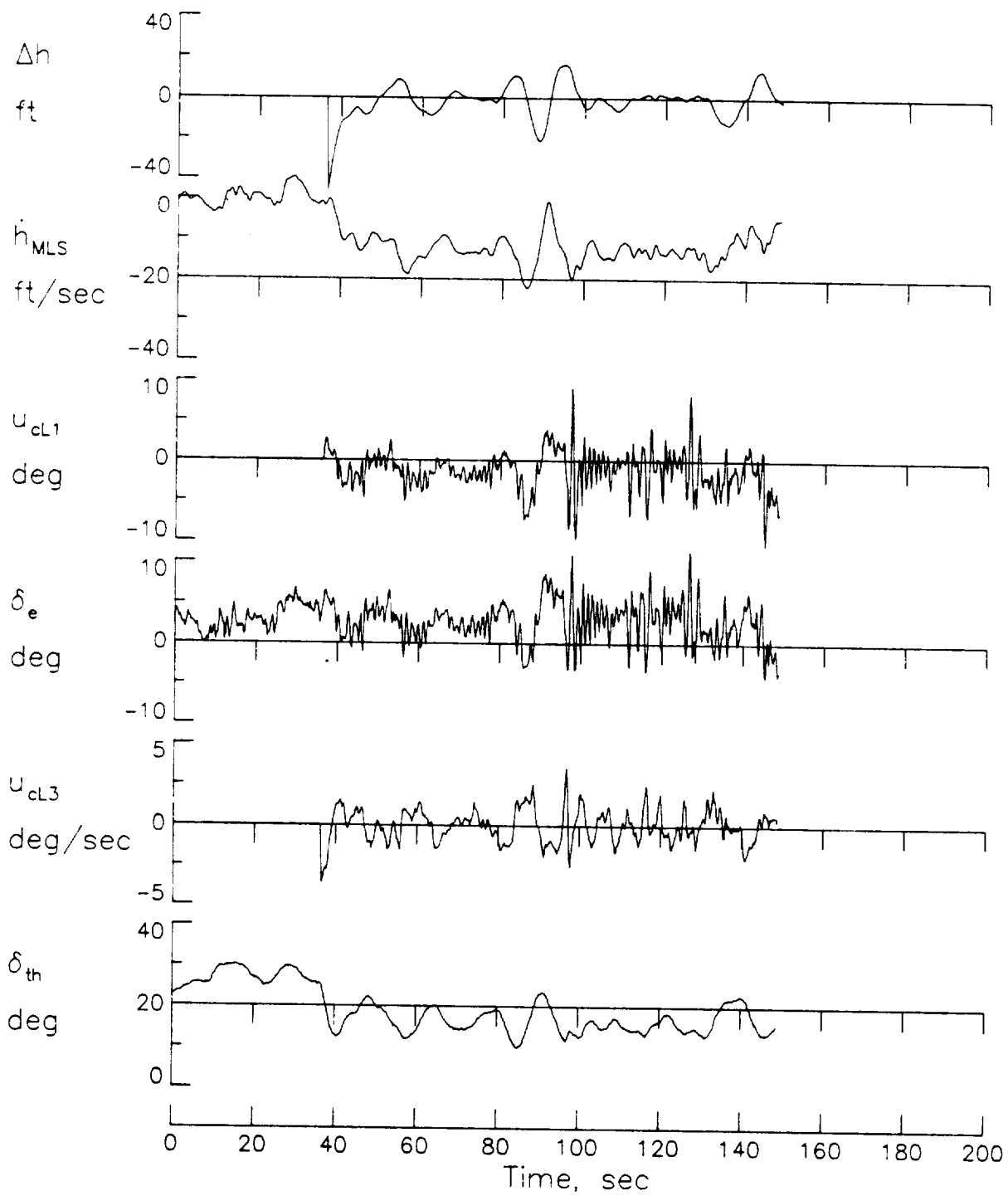


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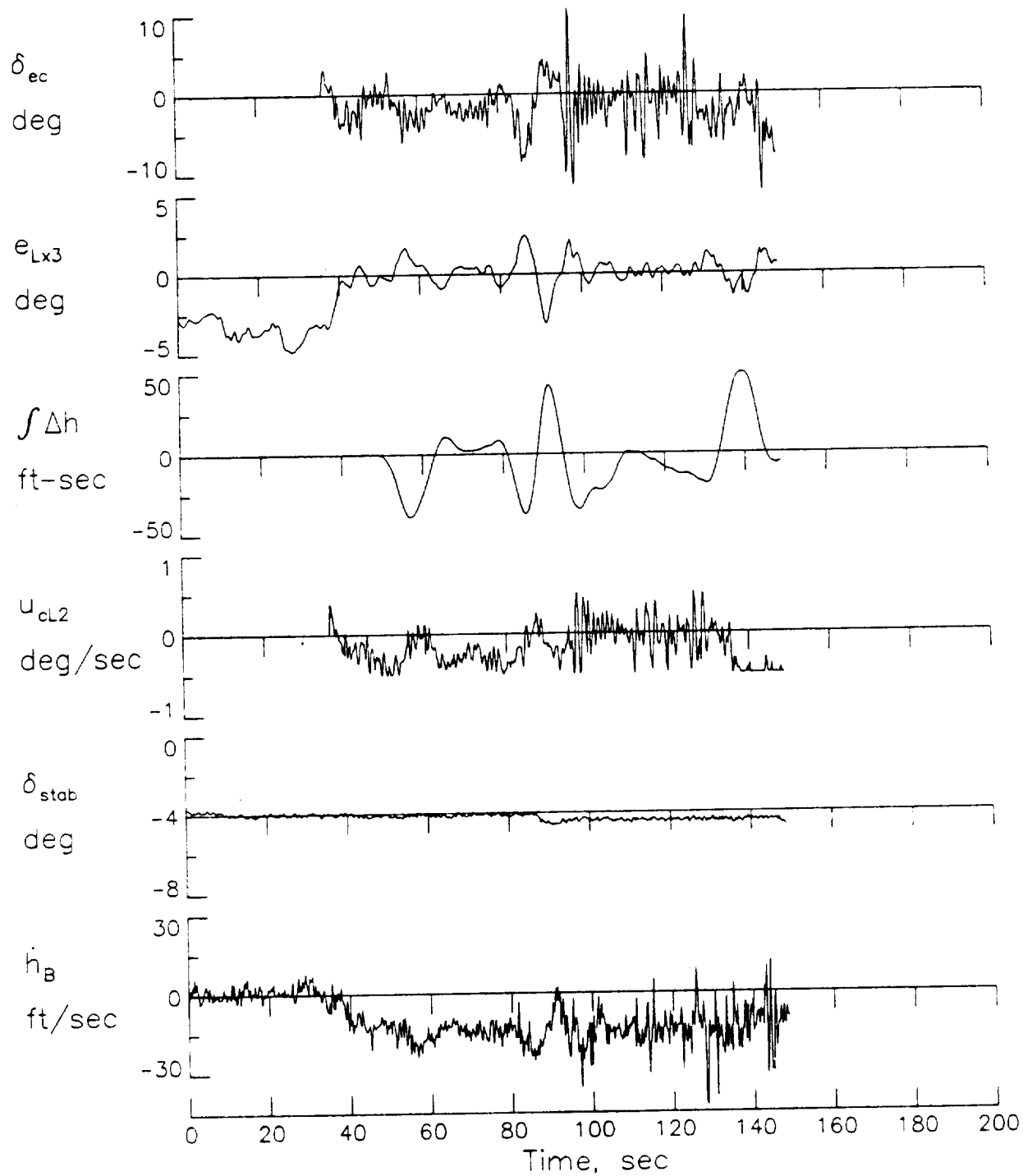


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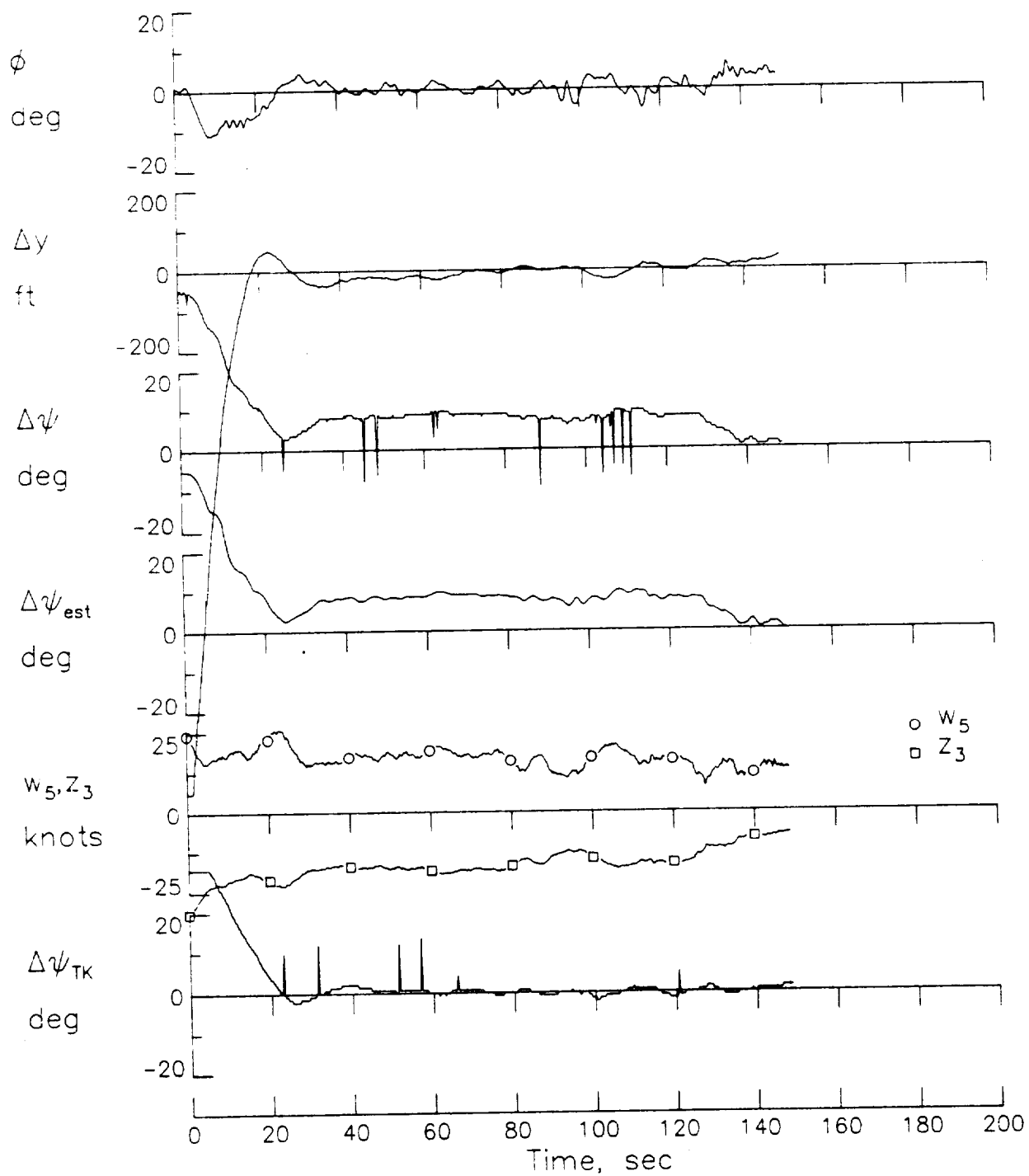


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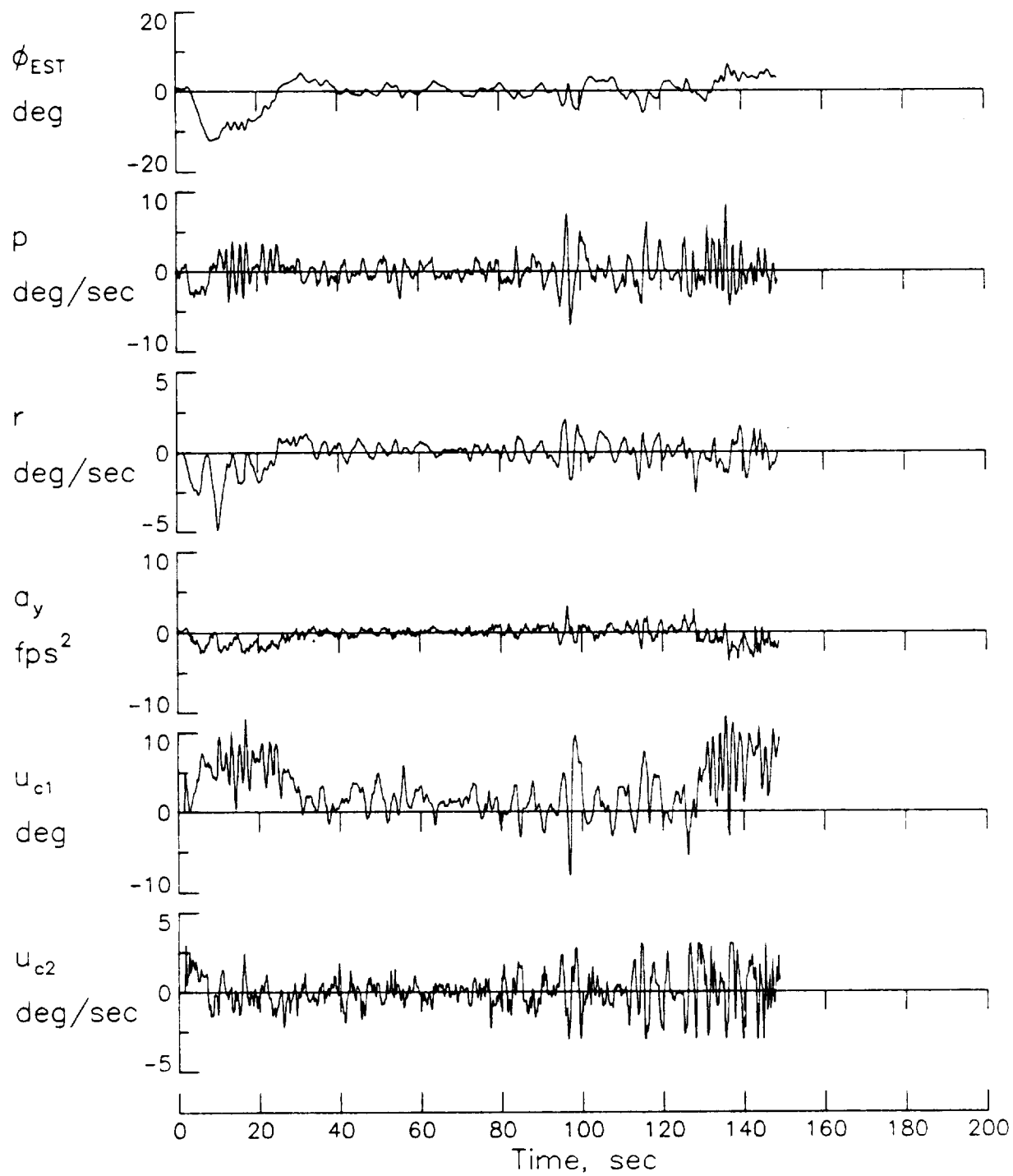


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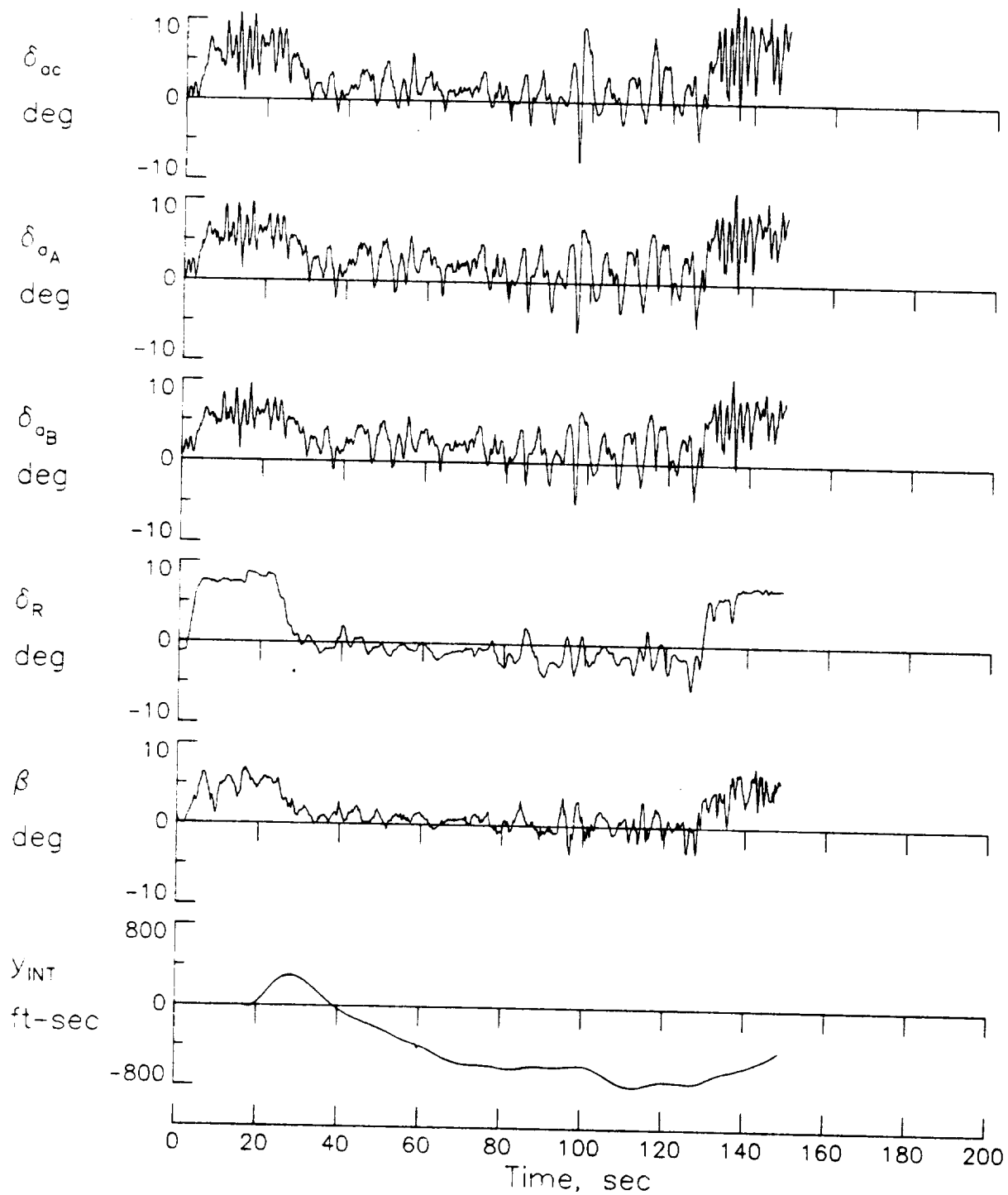


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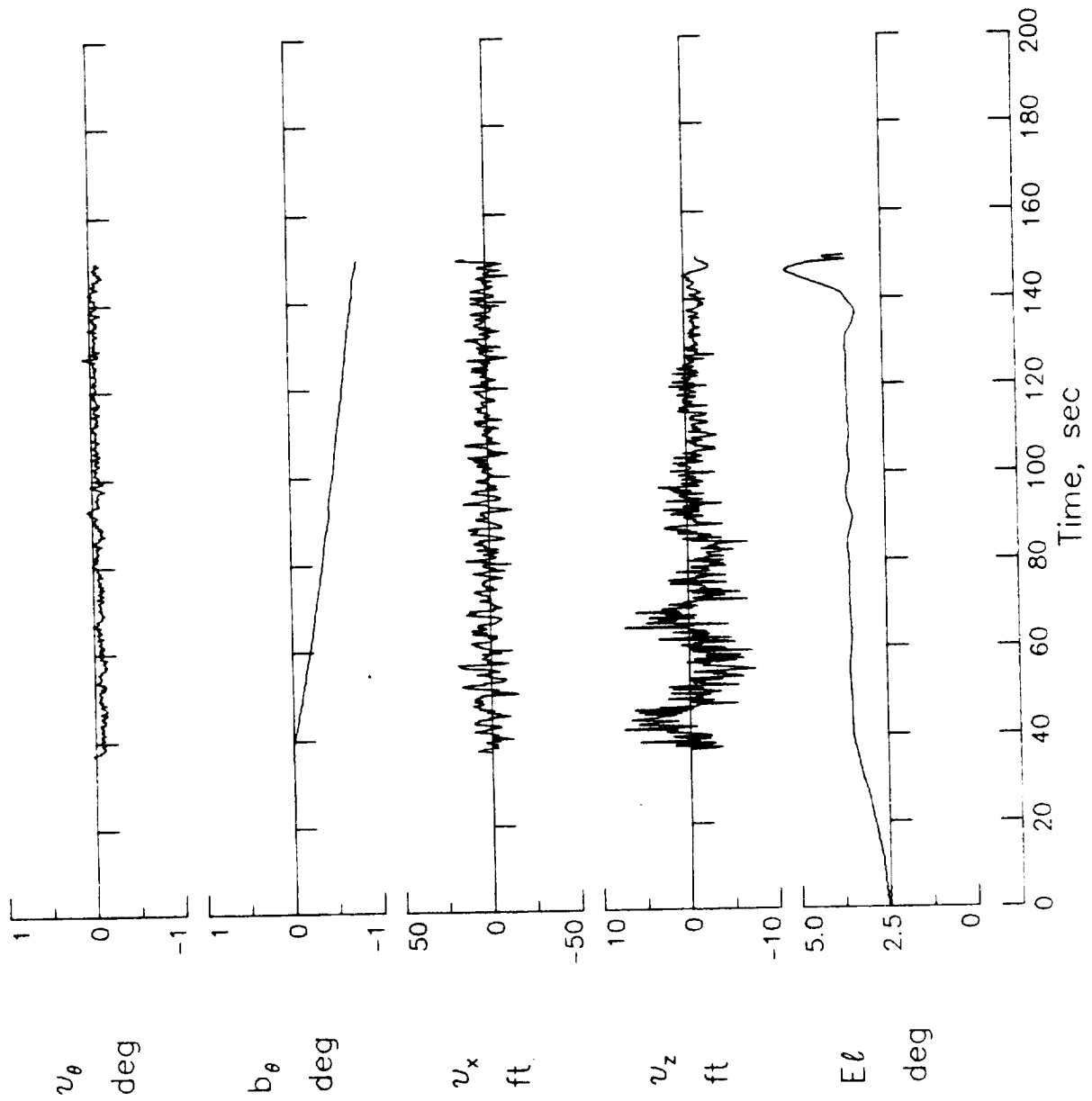


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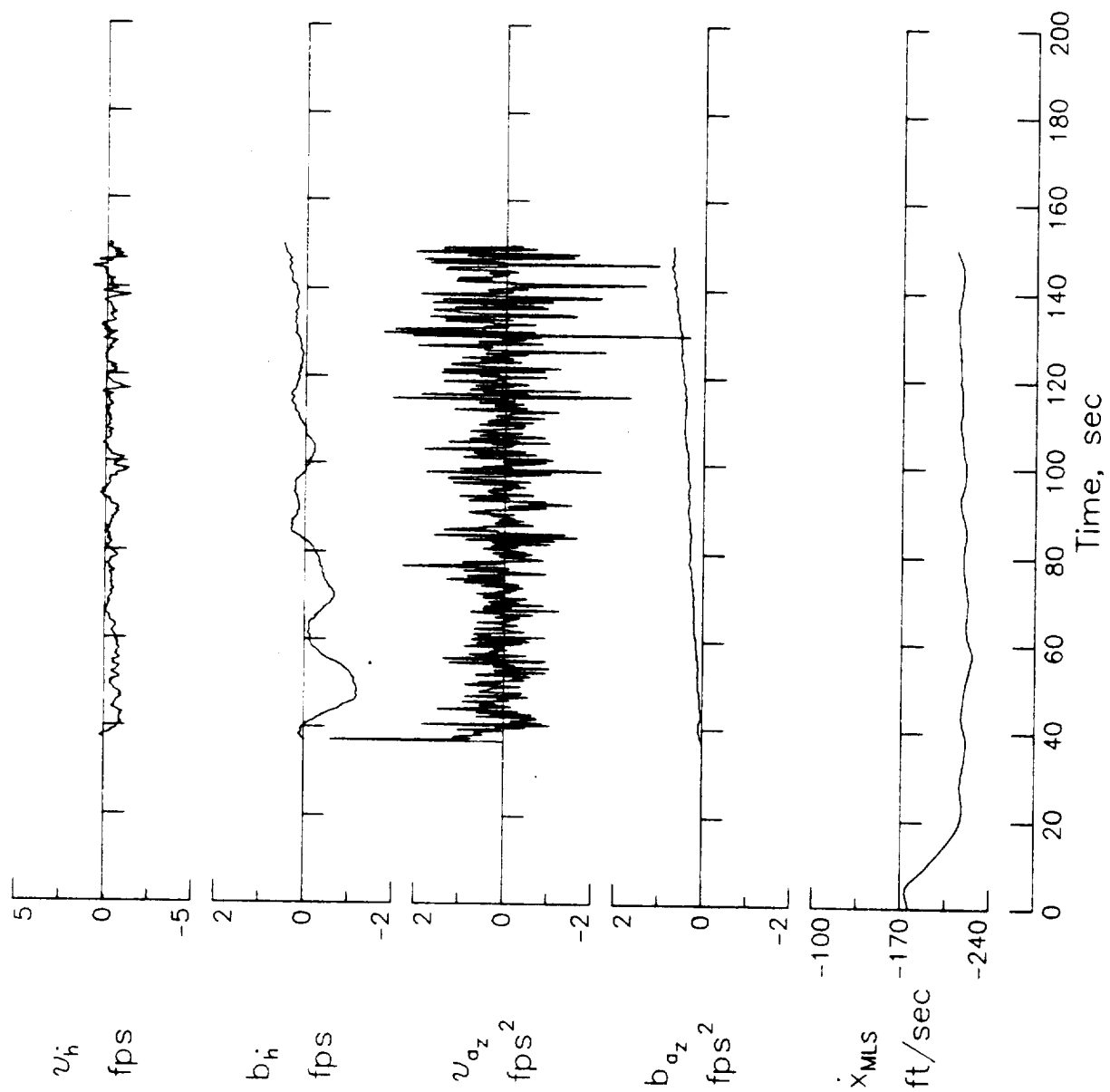


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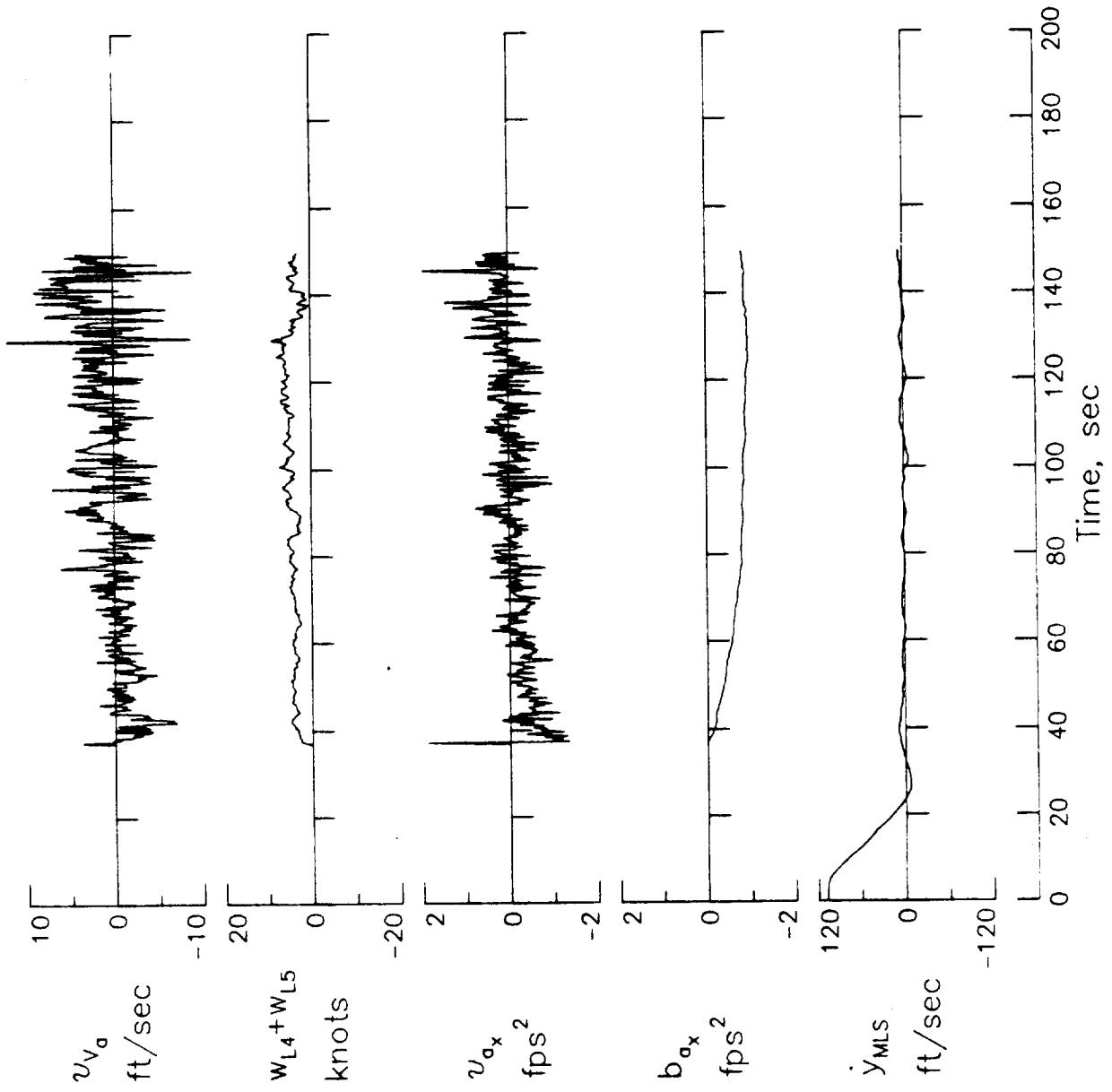


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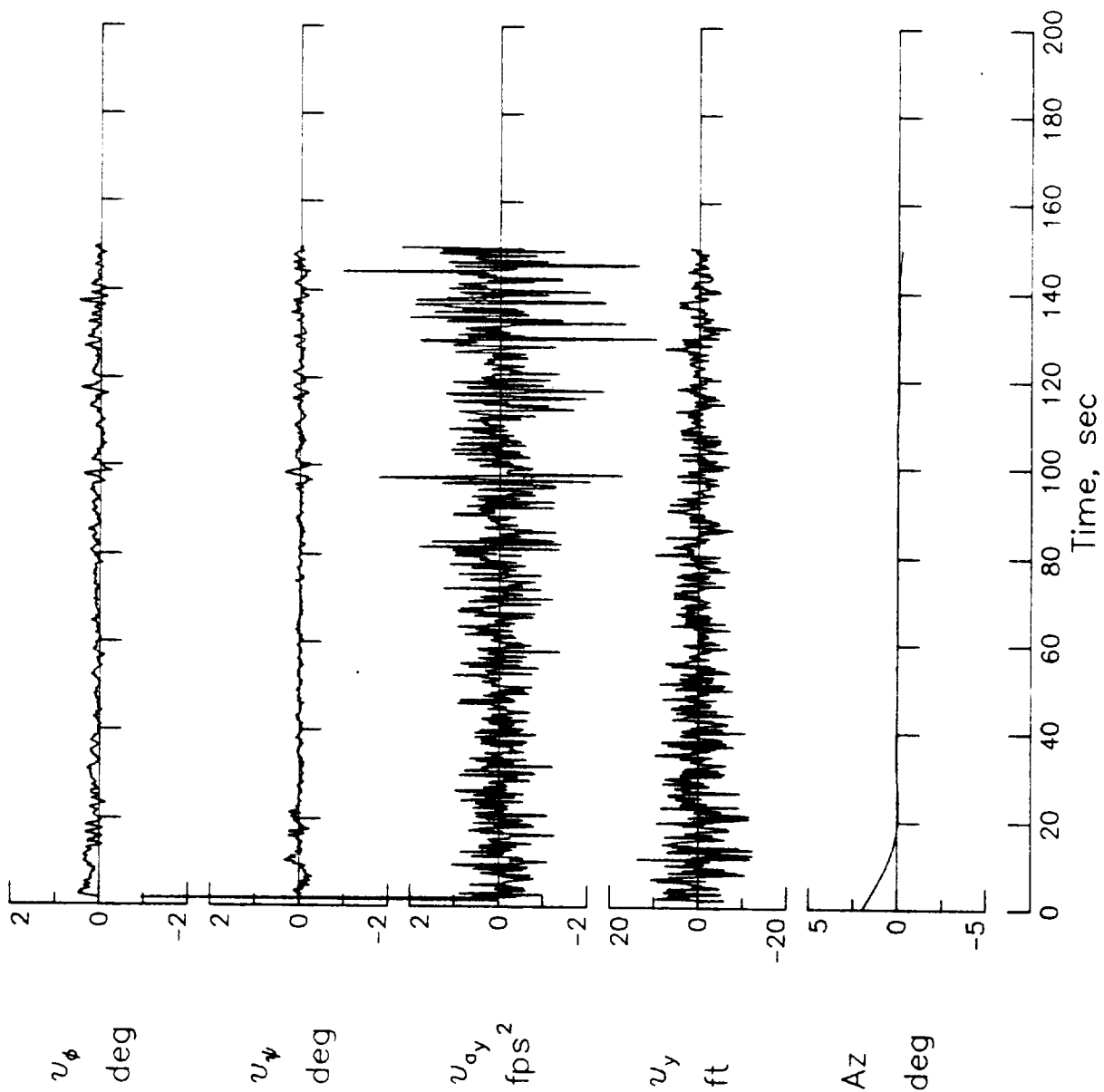


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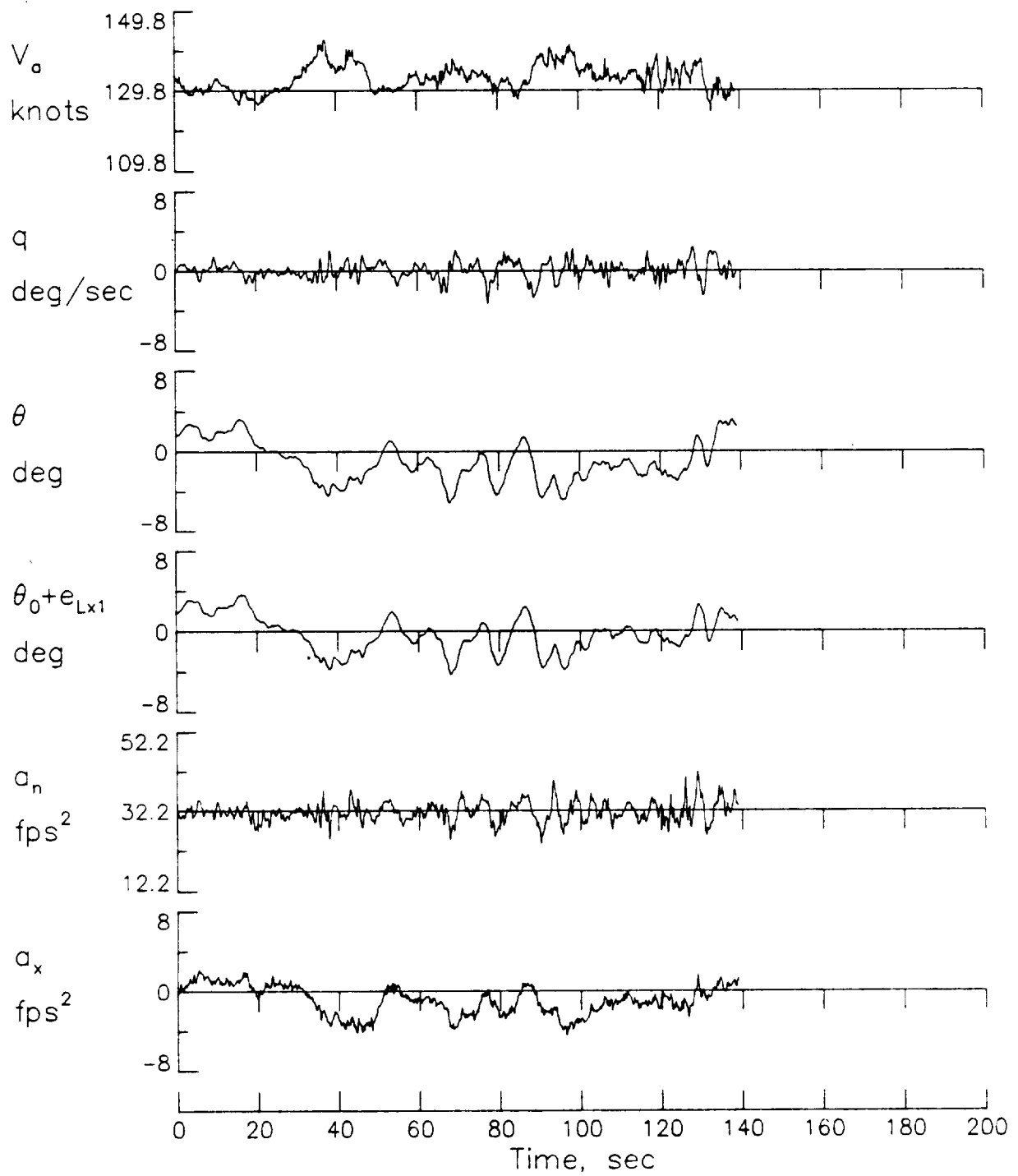


Figure 26. Flight Data for DIALS Flight Test R364, Run 5

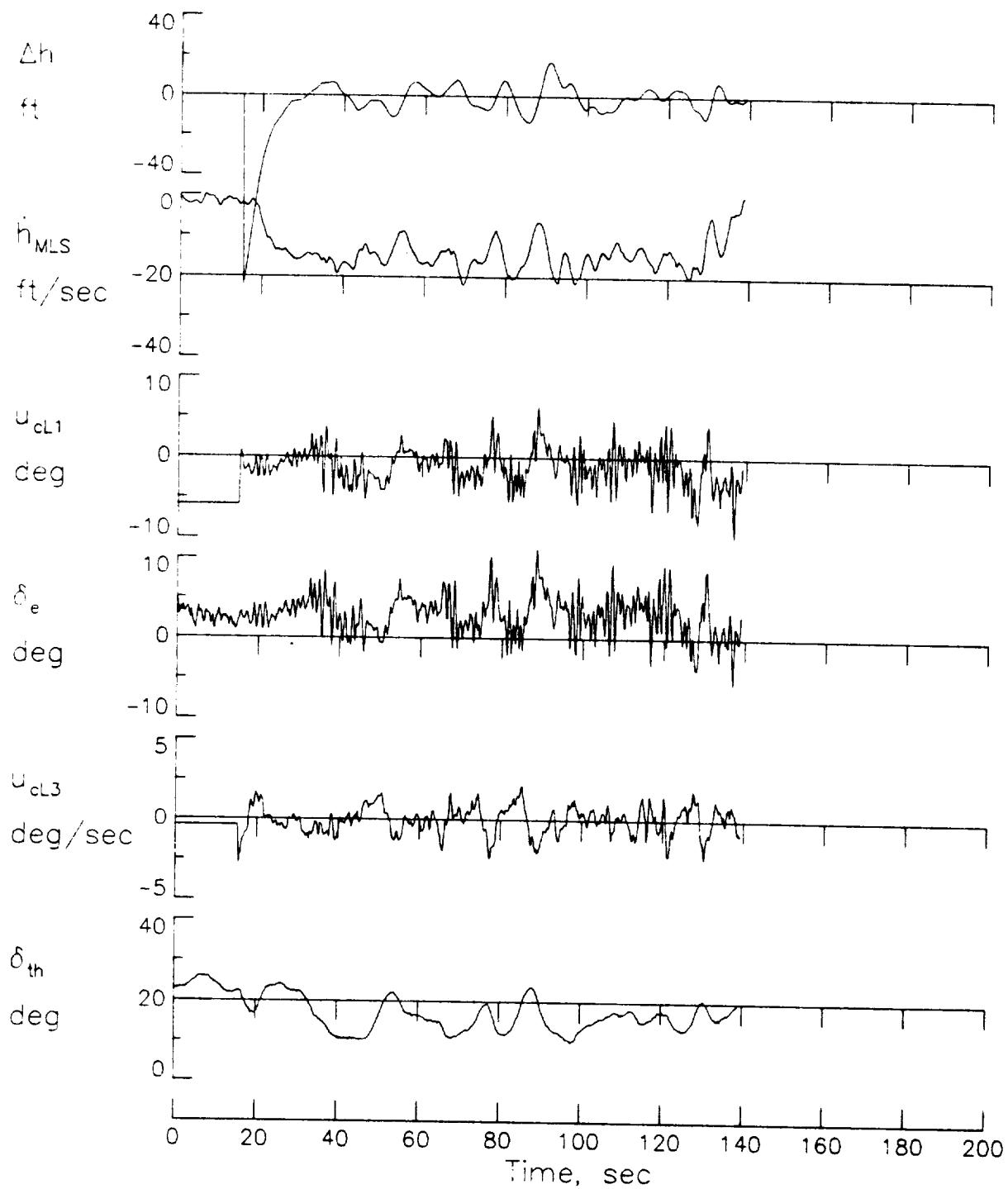


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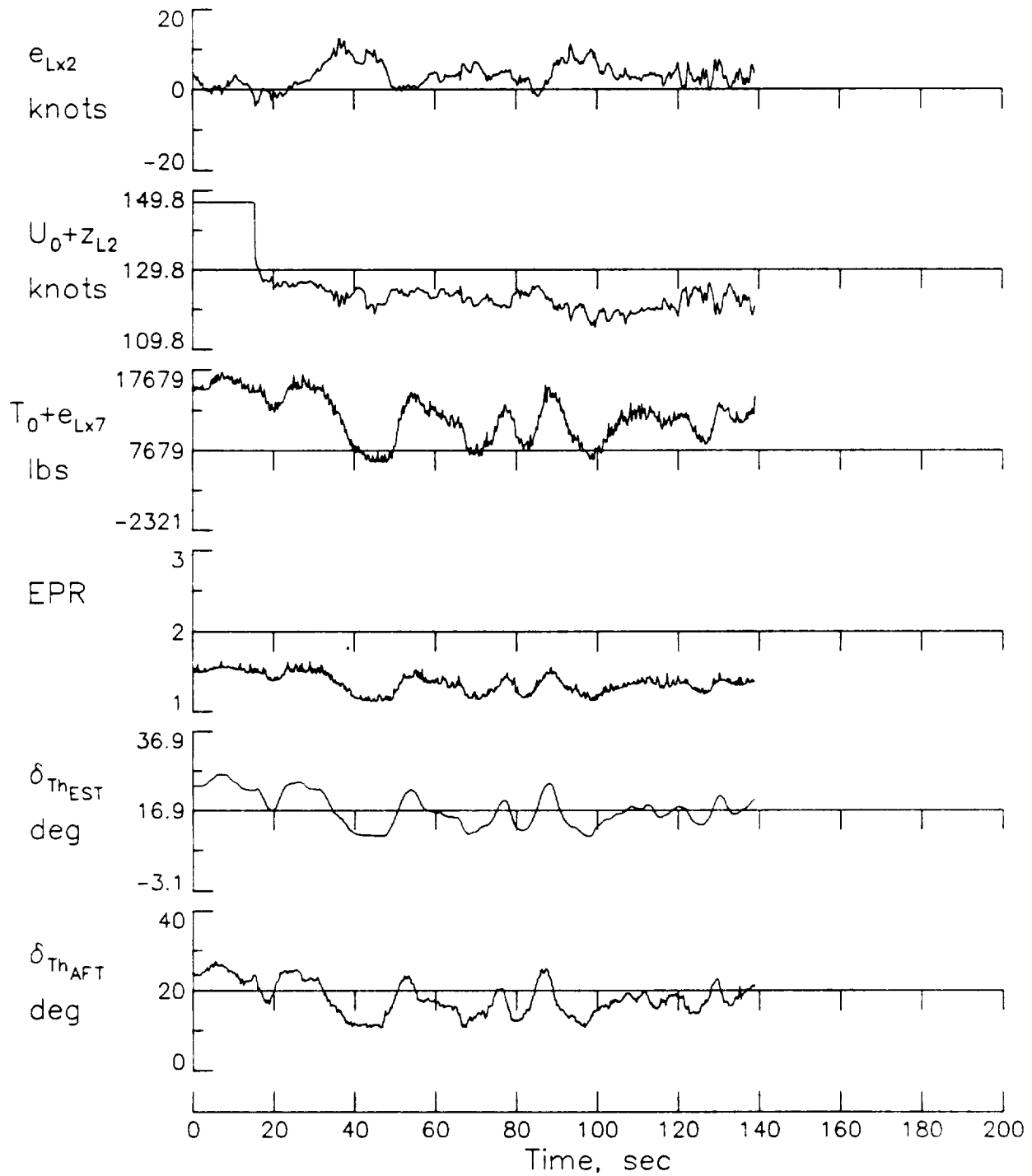


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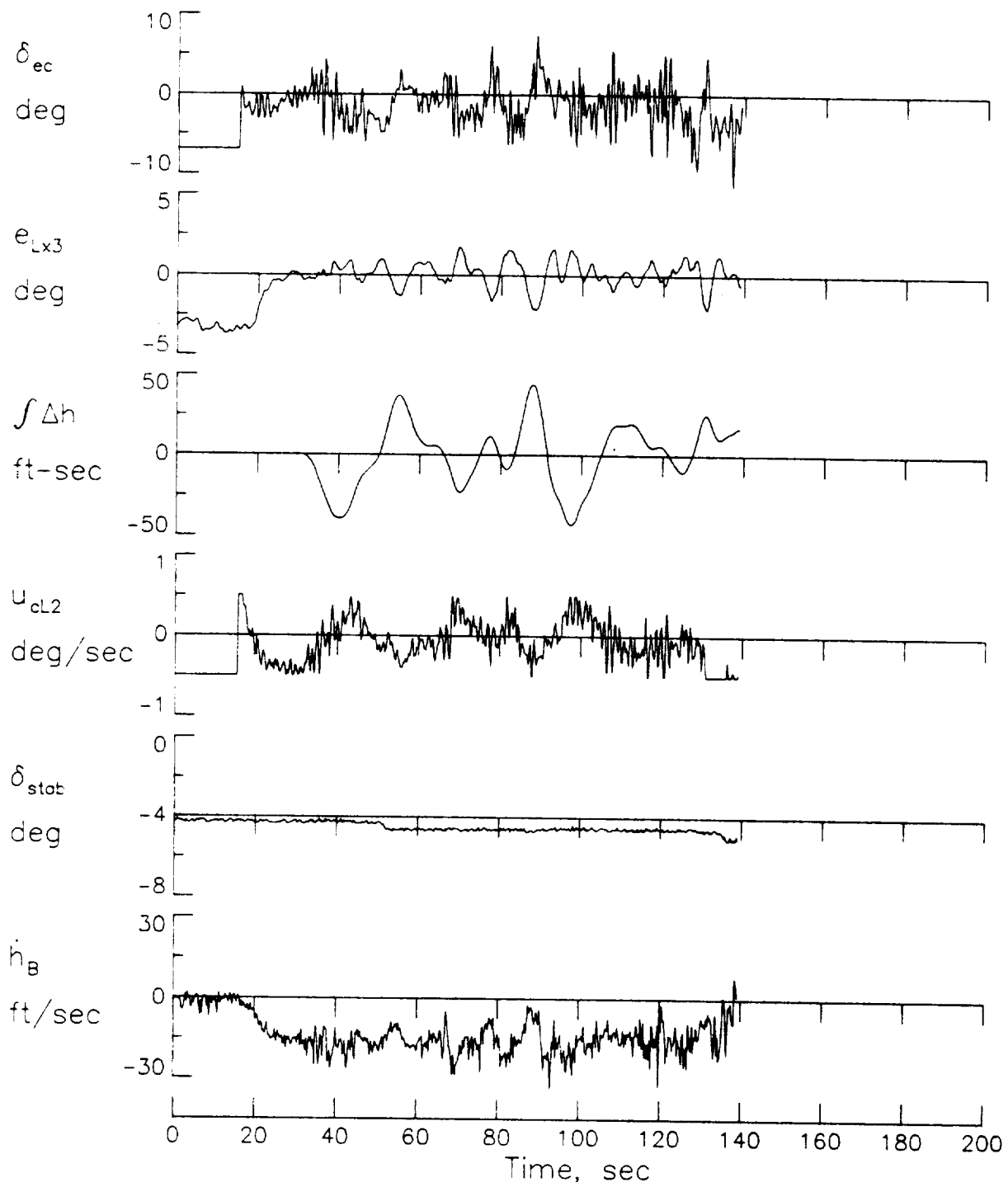


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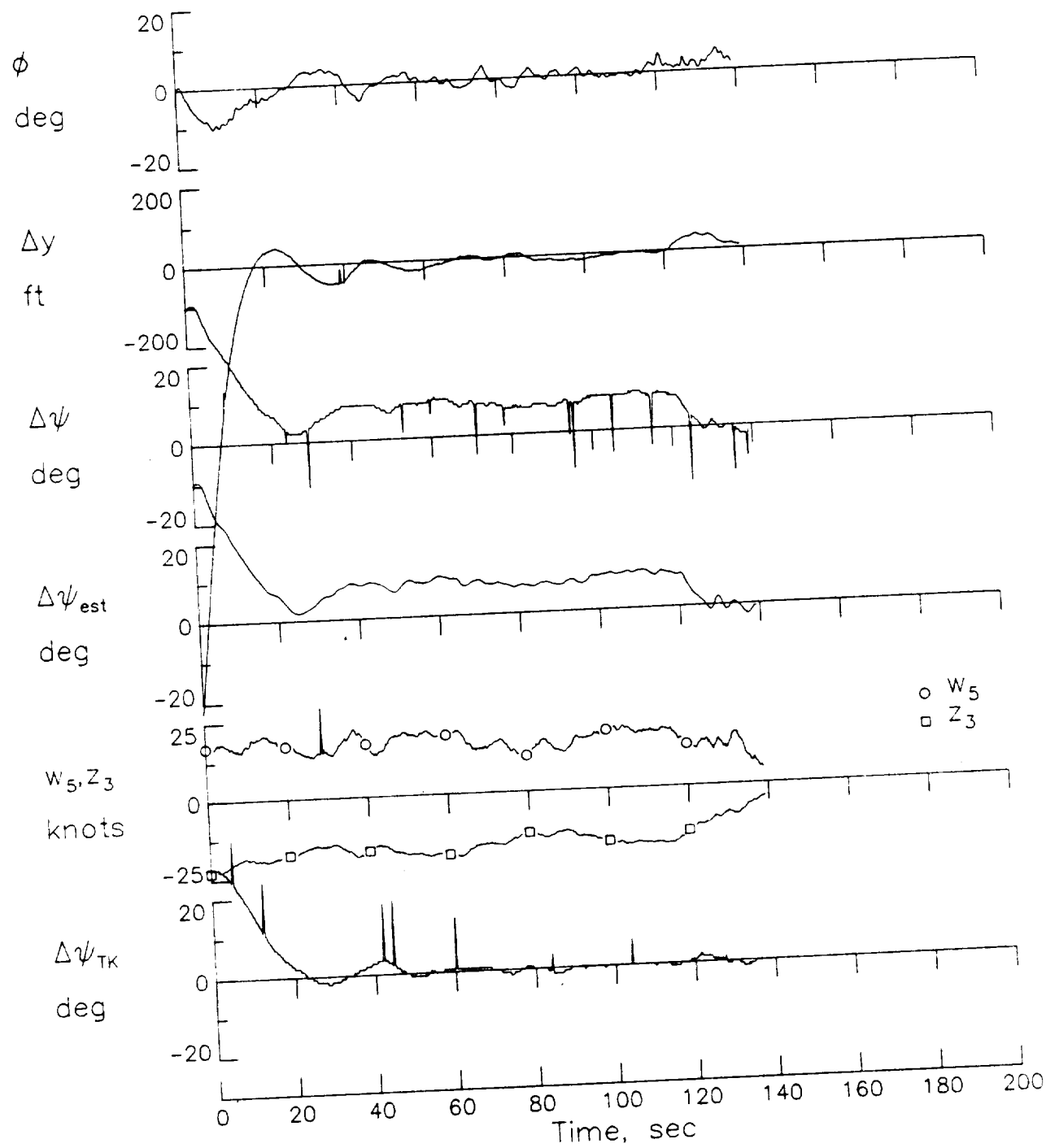


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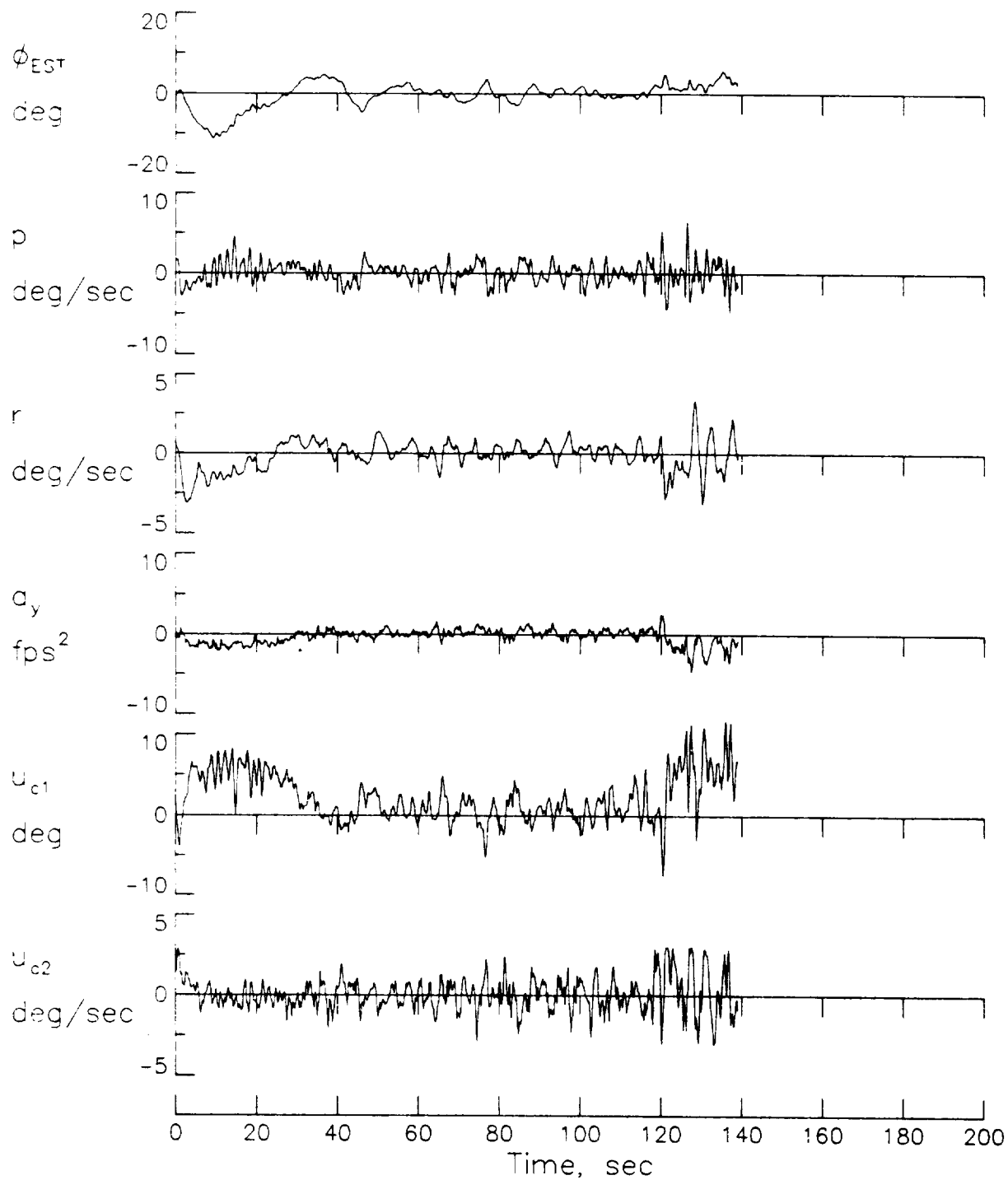


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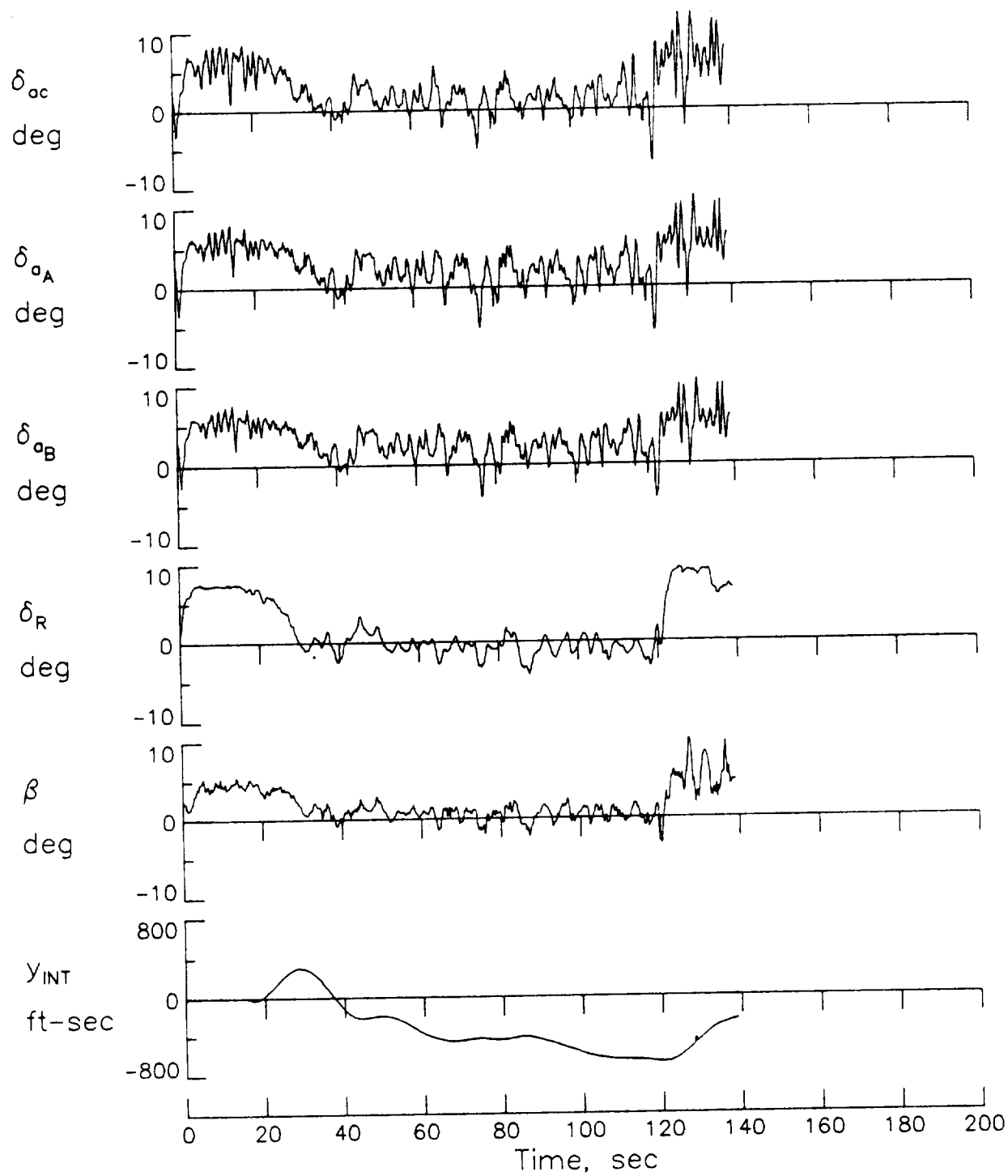


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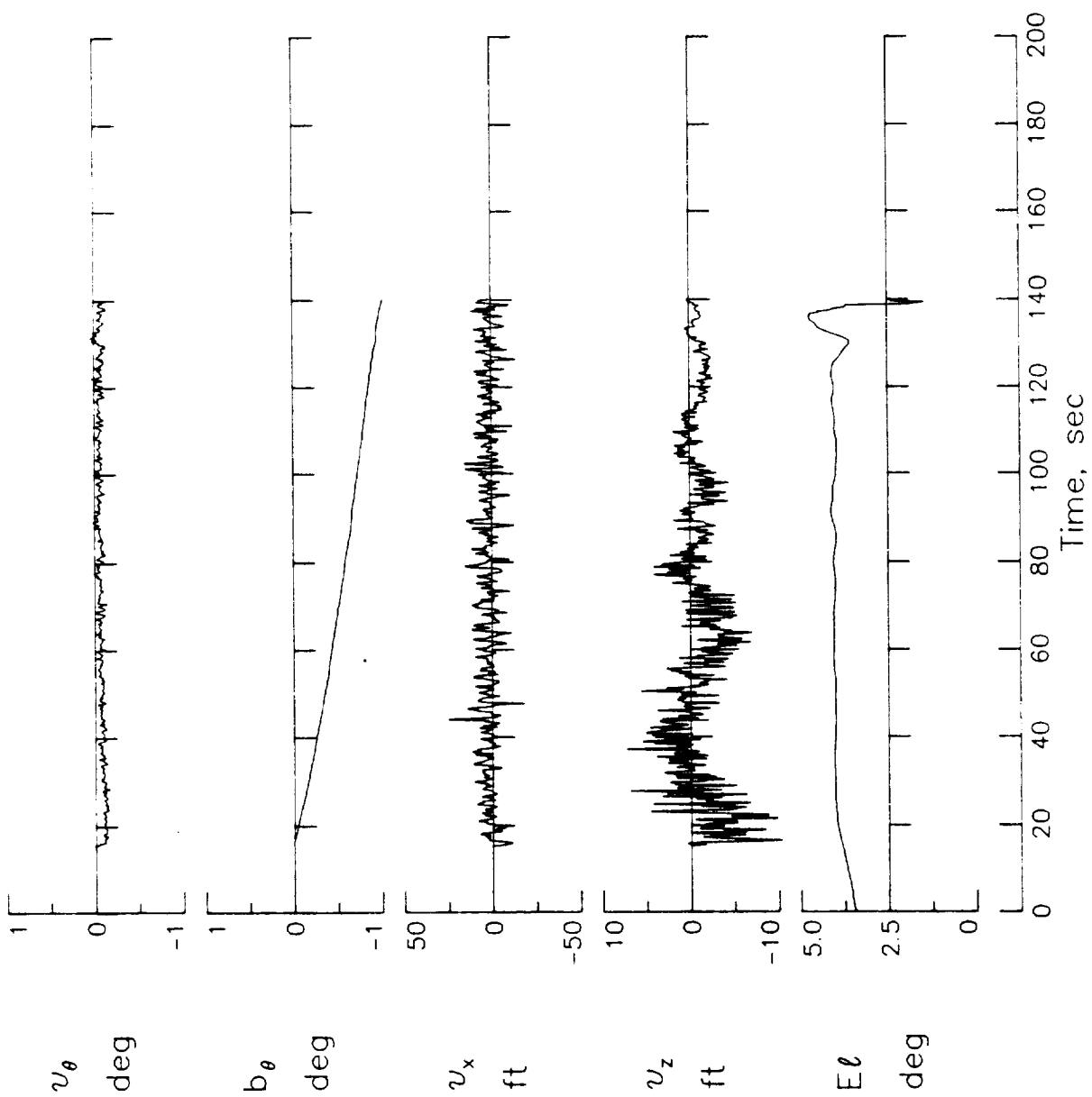


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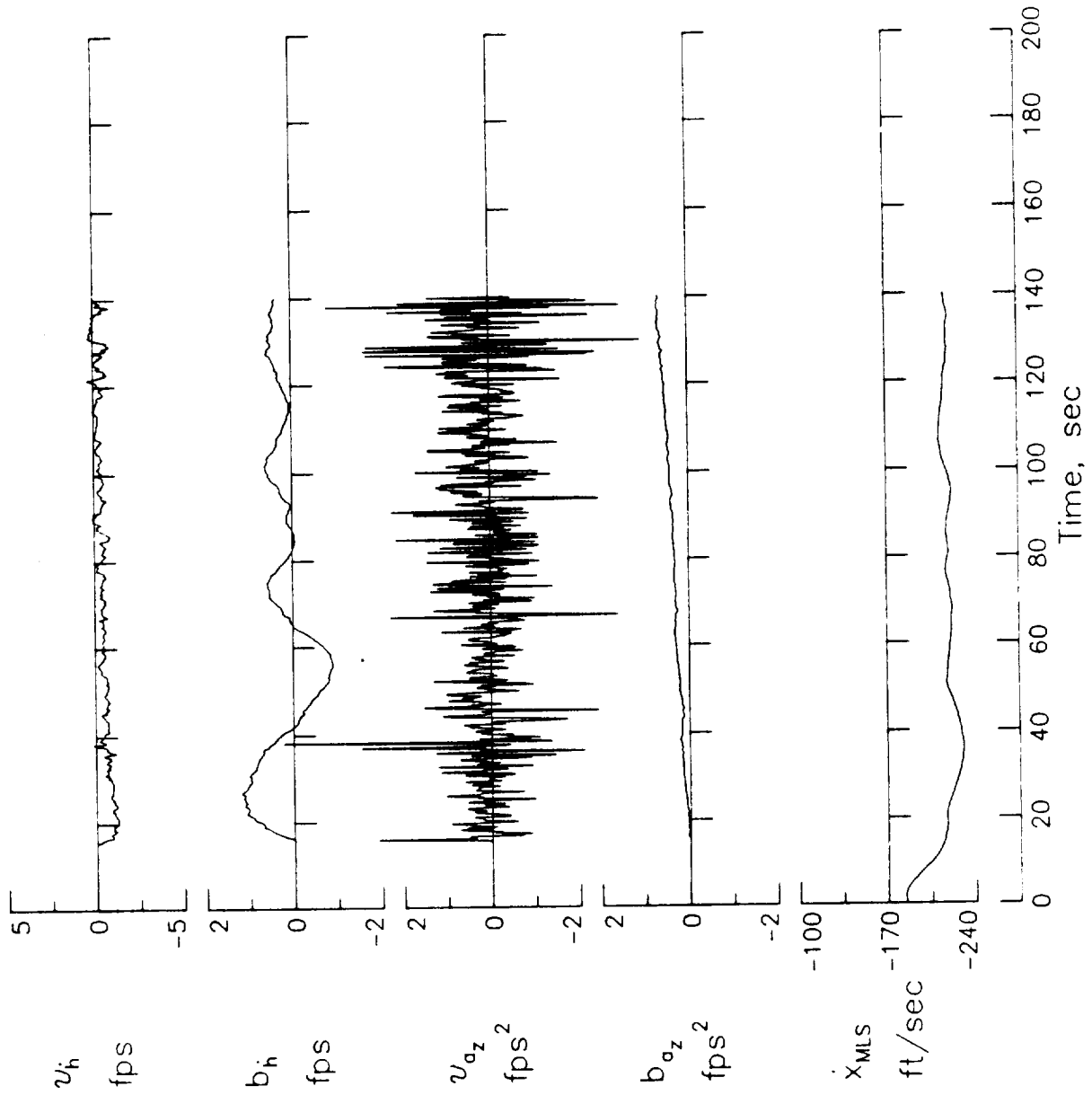


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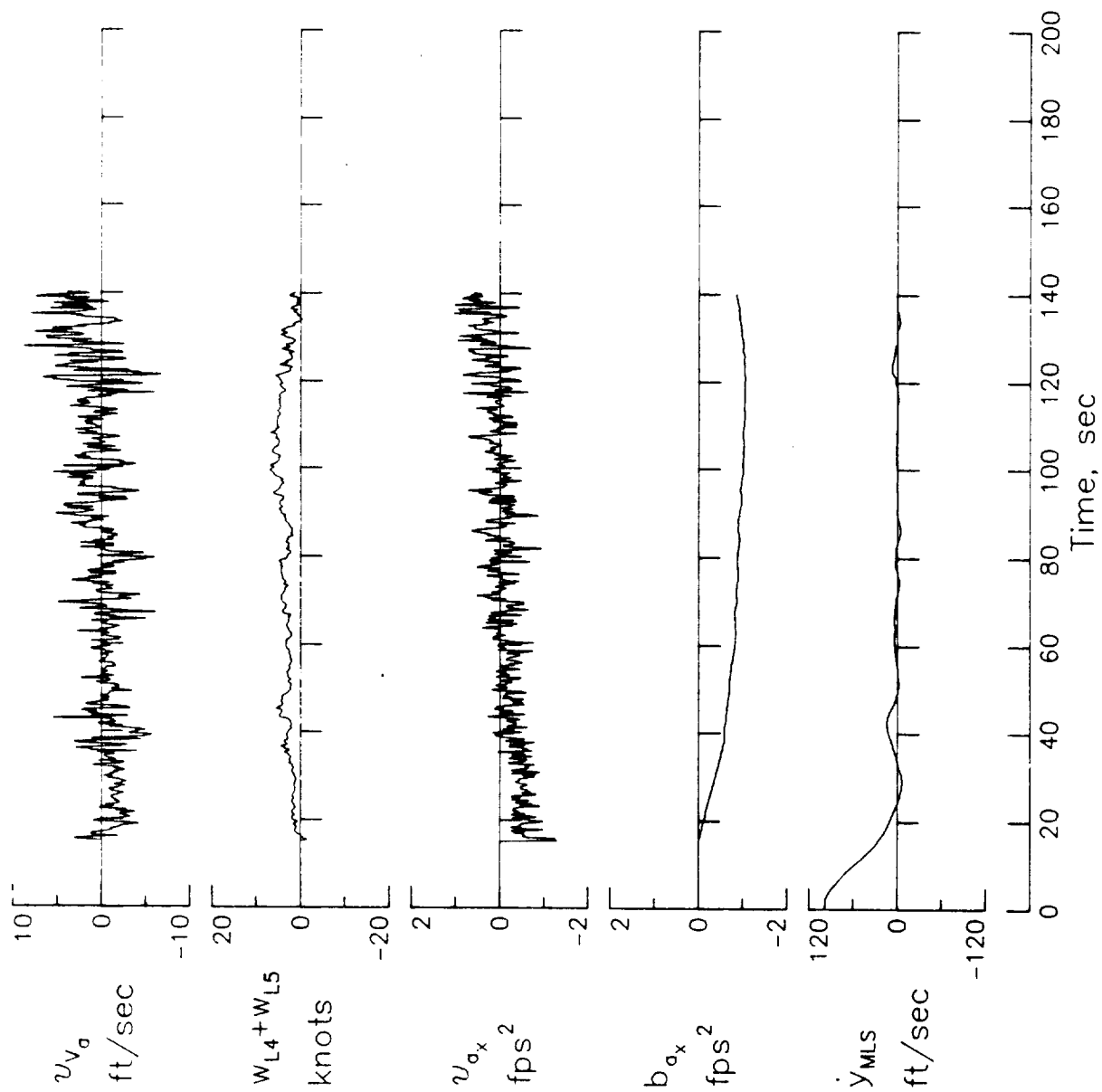


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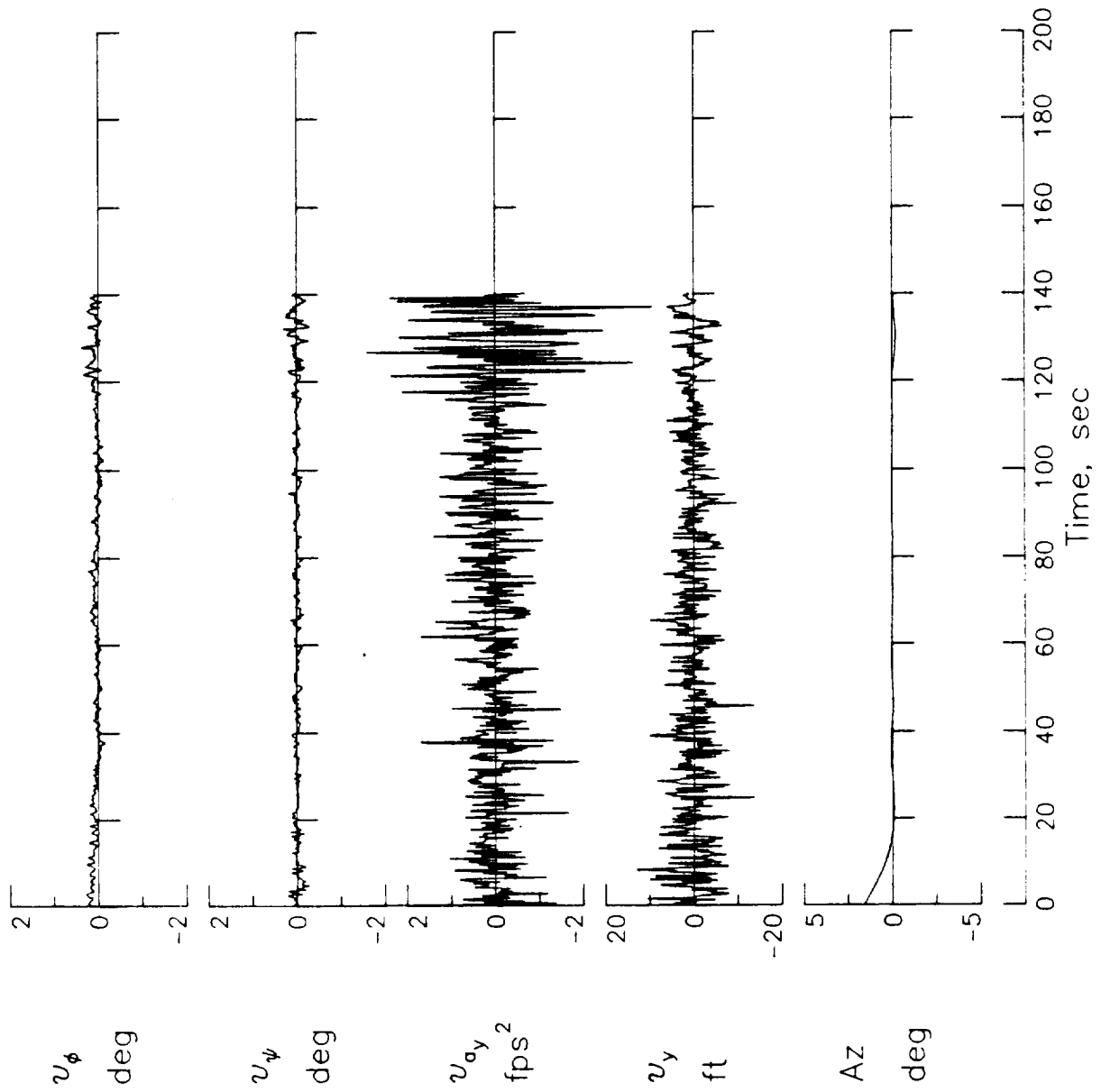


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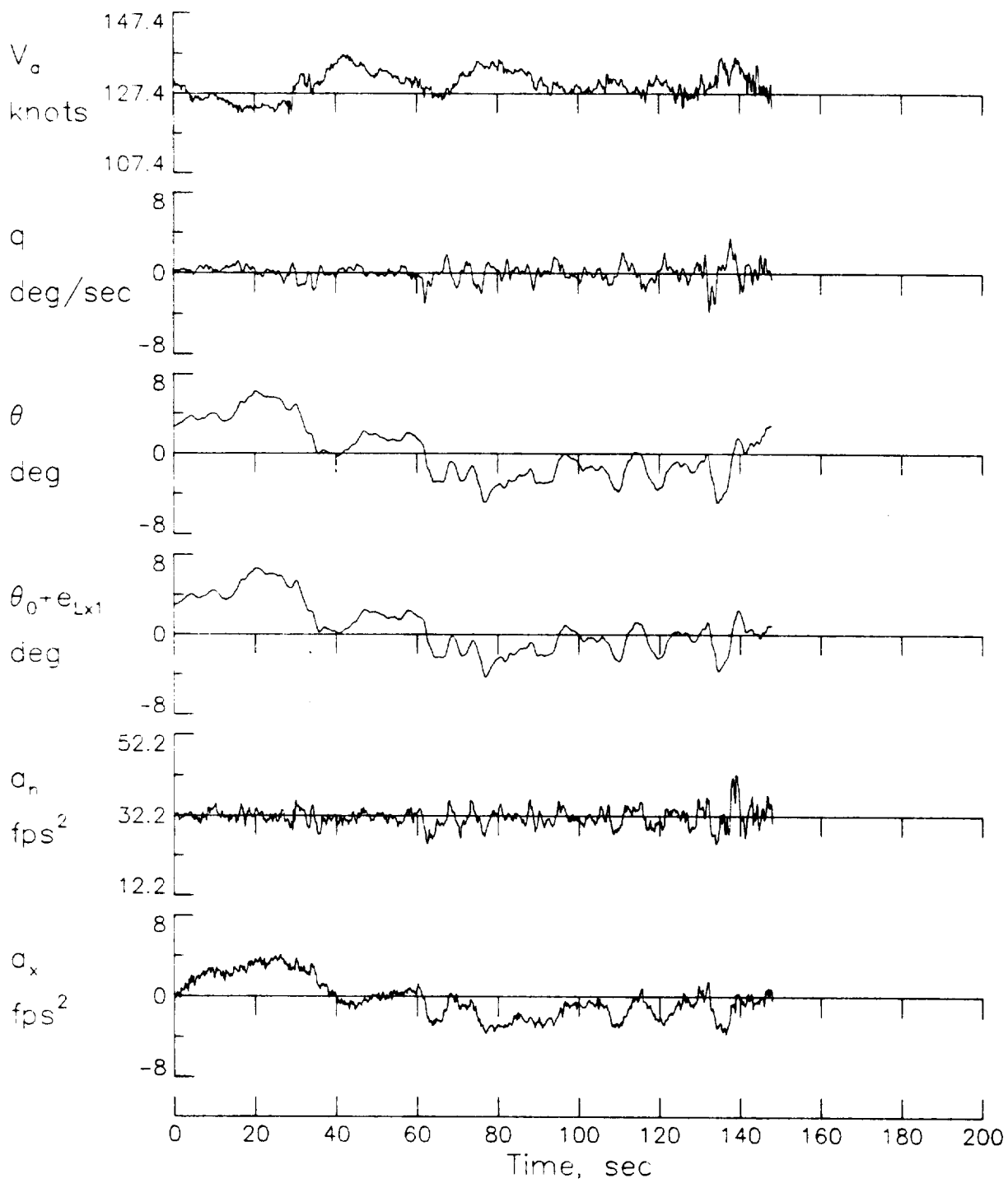


Figure 27. Flight Data for DIALS Flight Test R364, Run 6

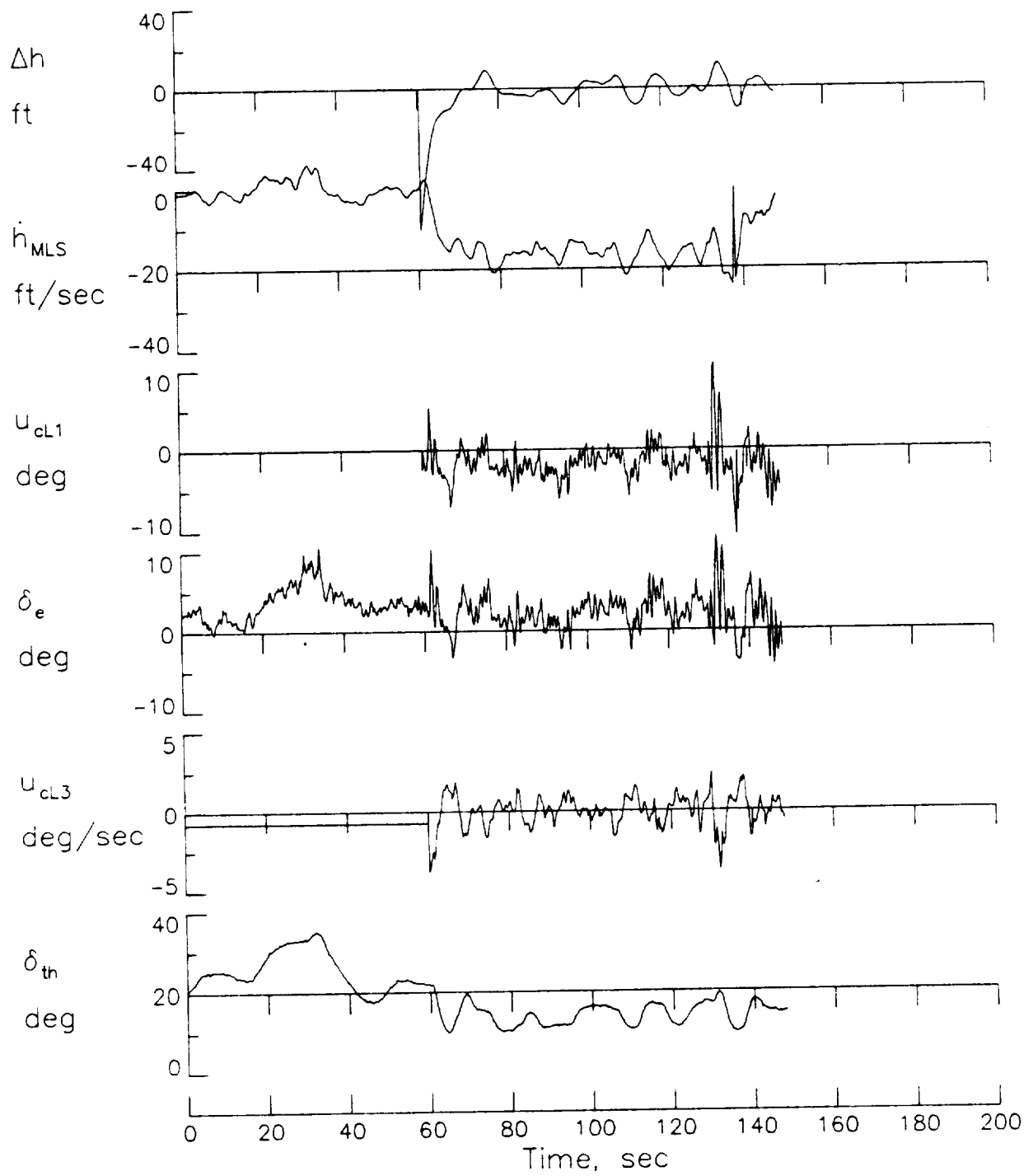


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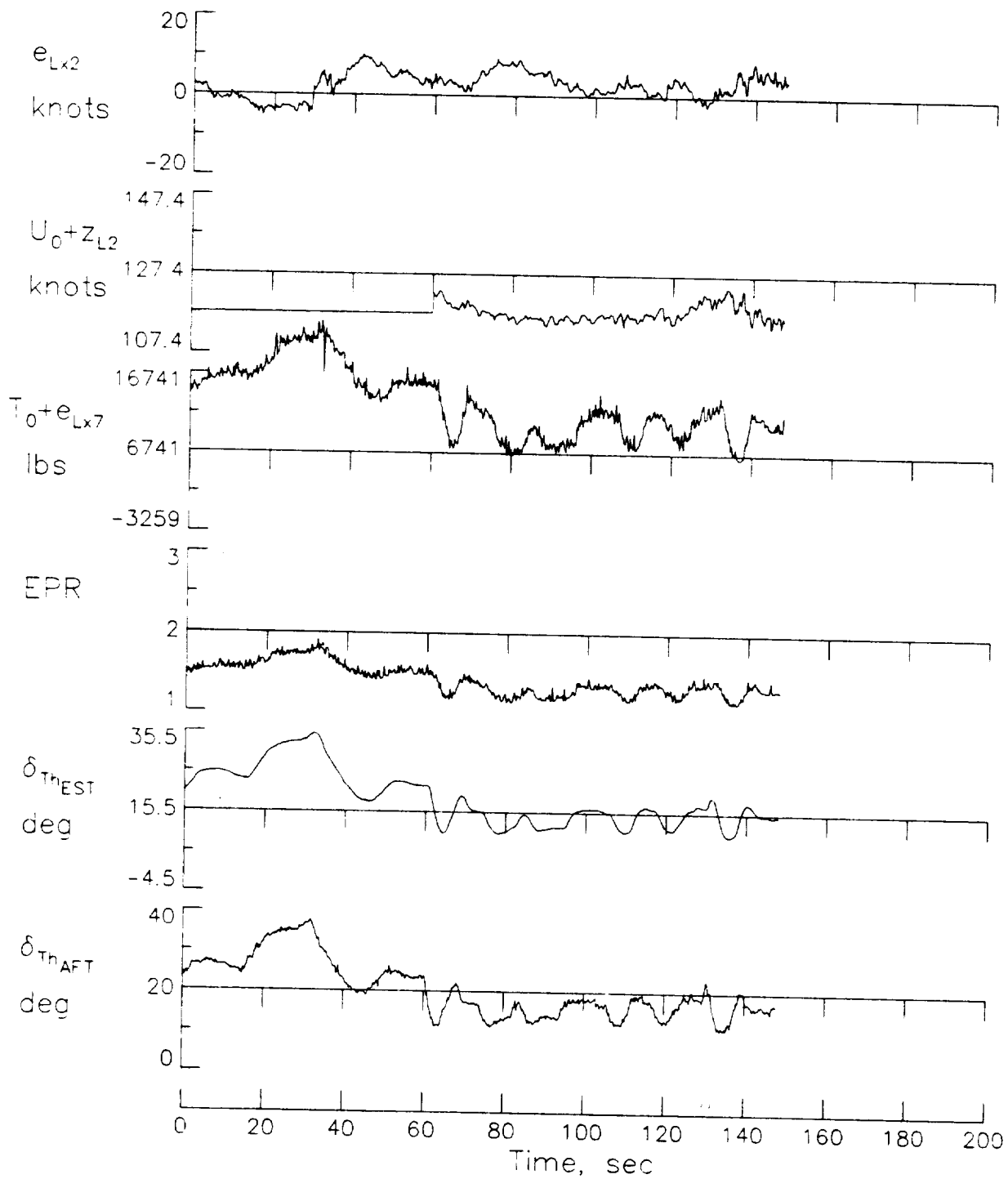


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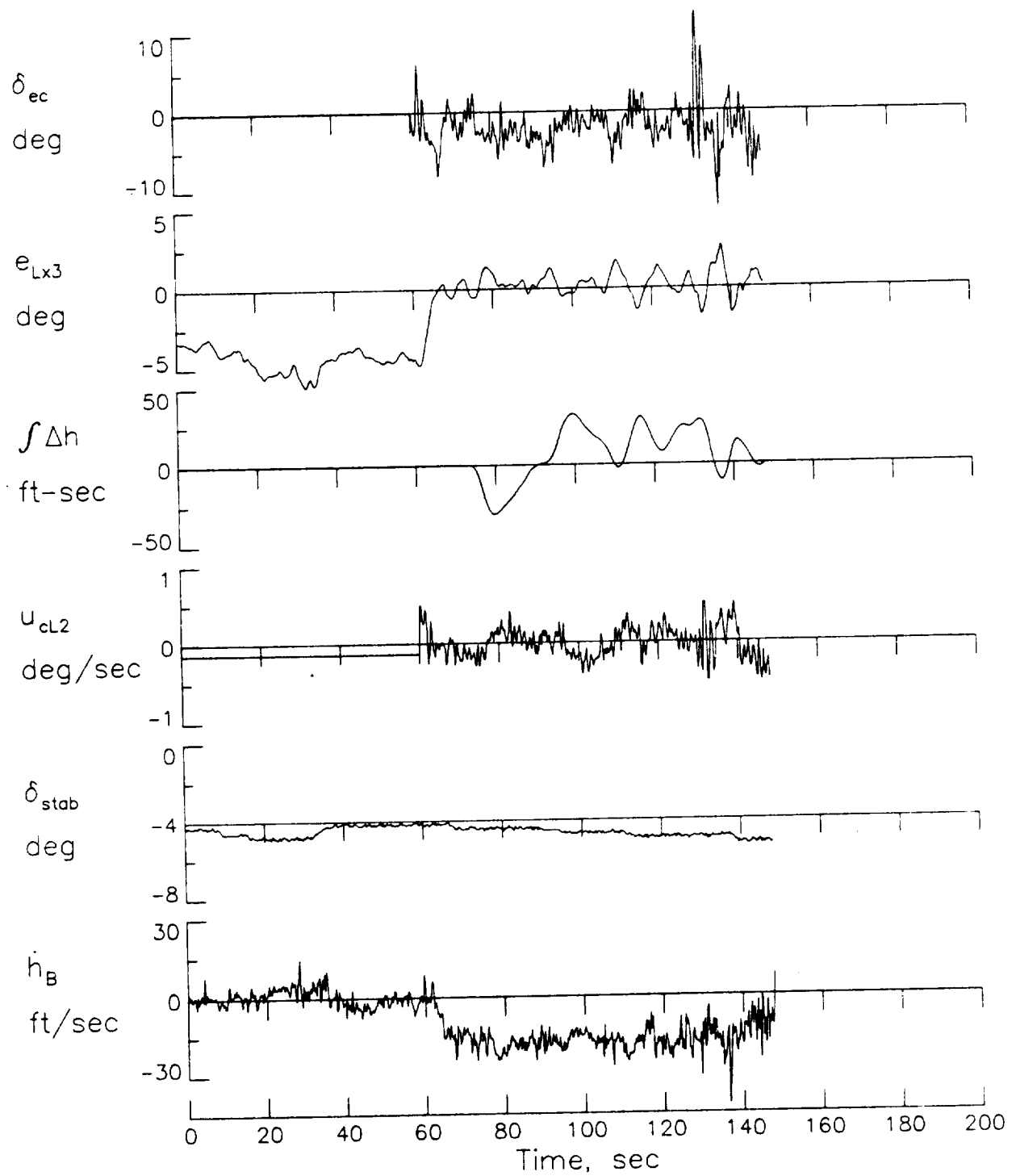


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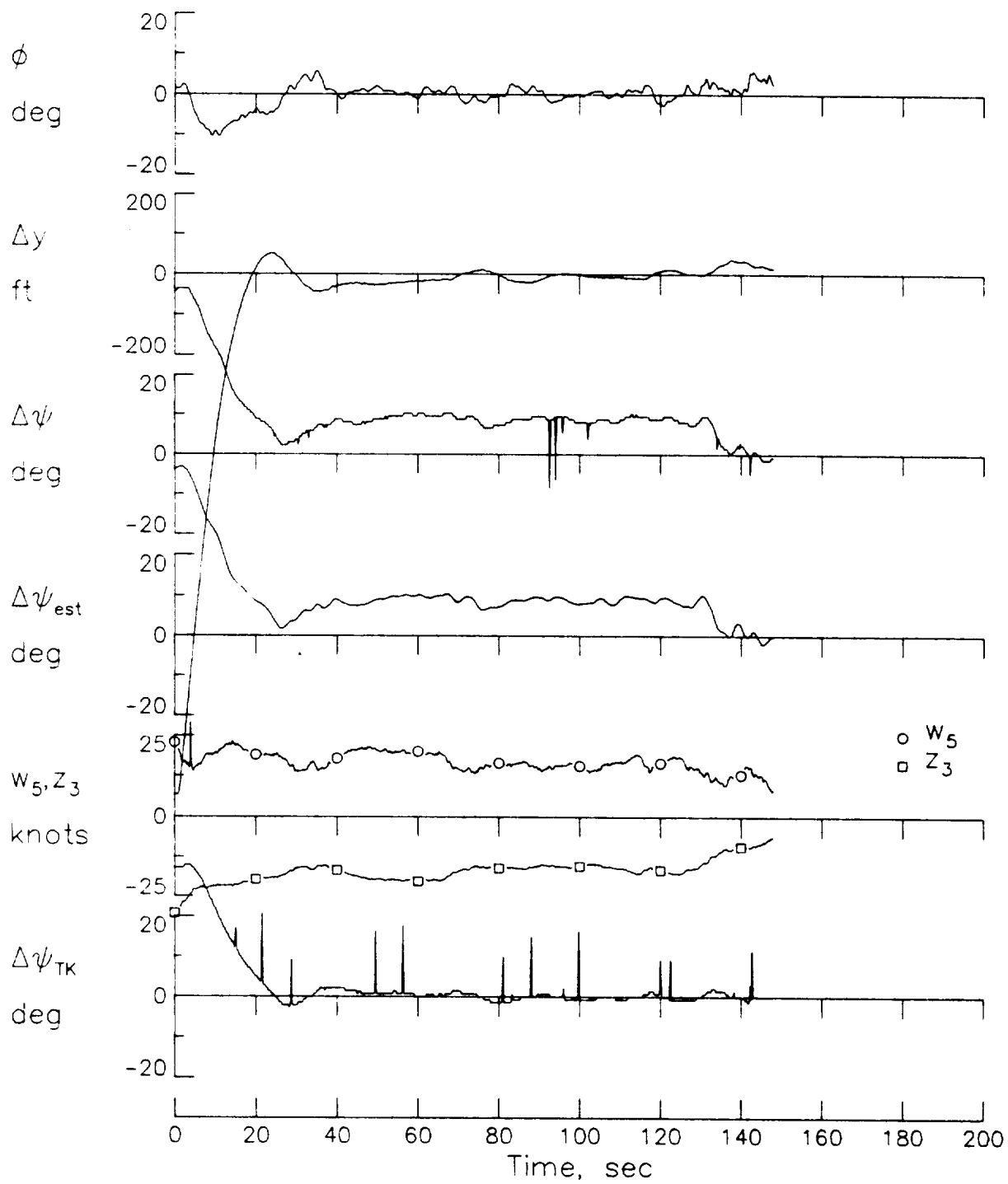


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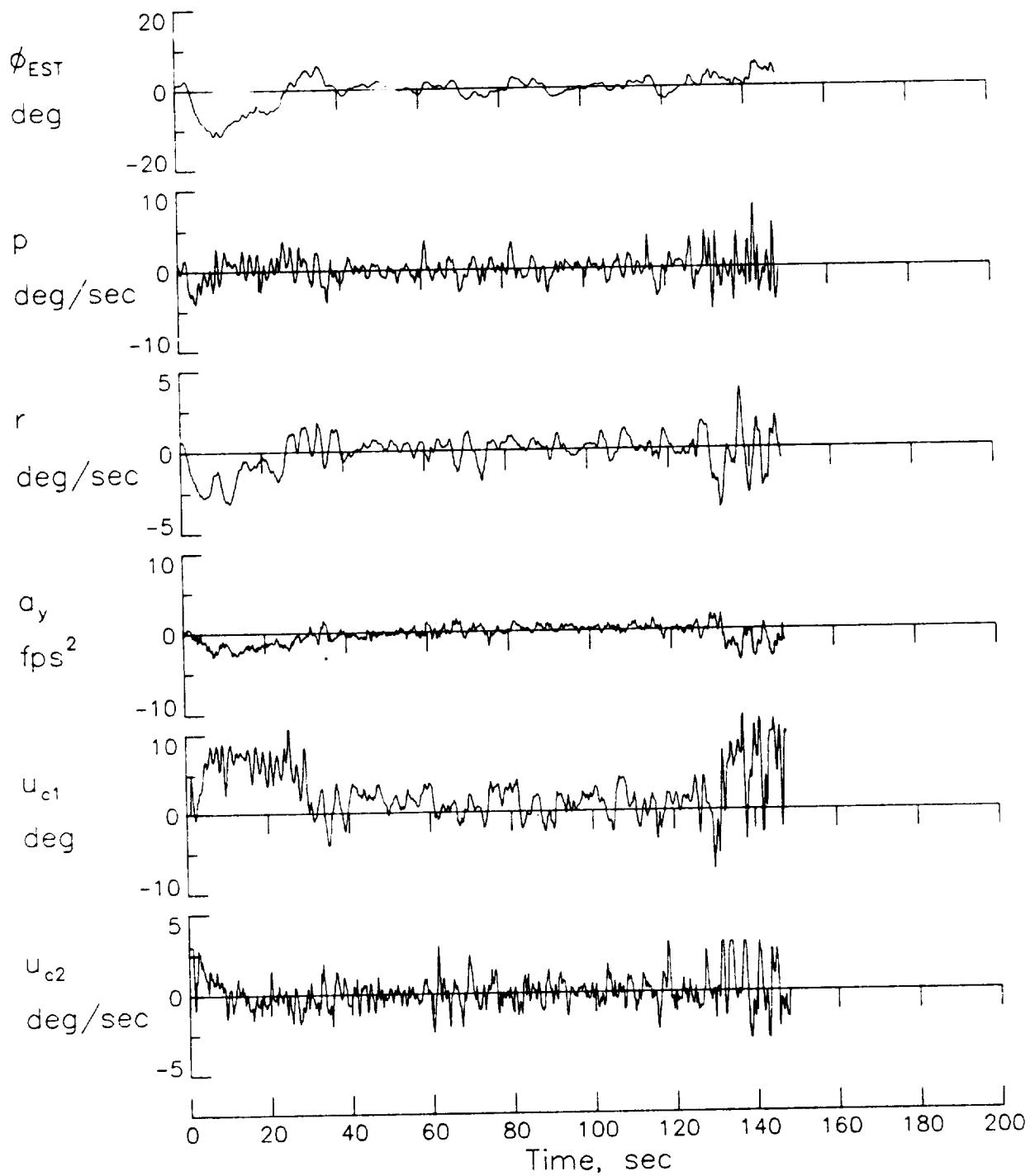


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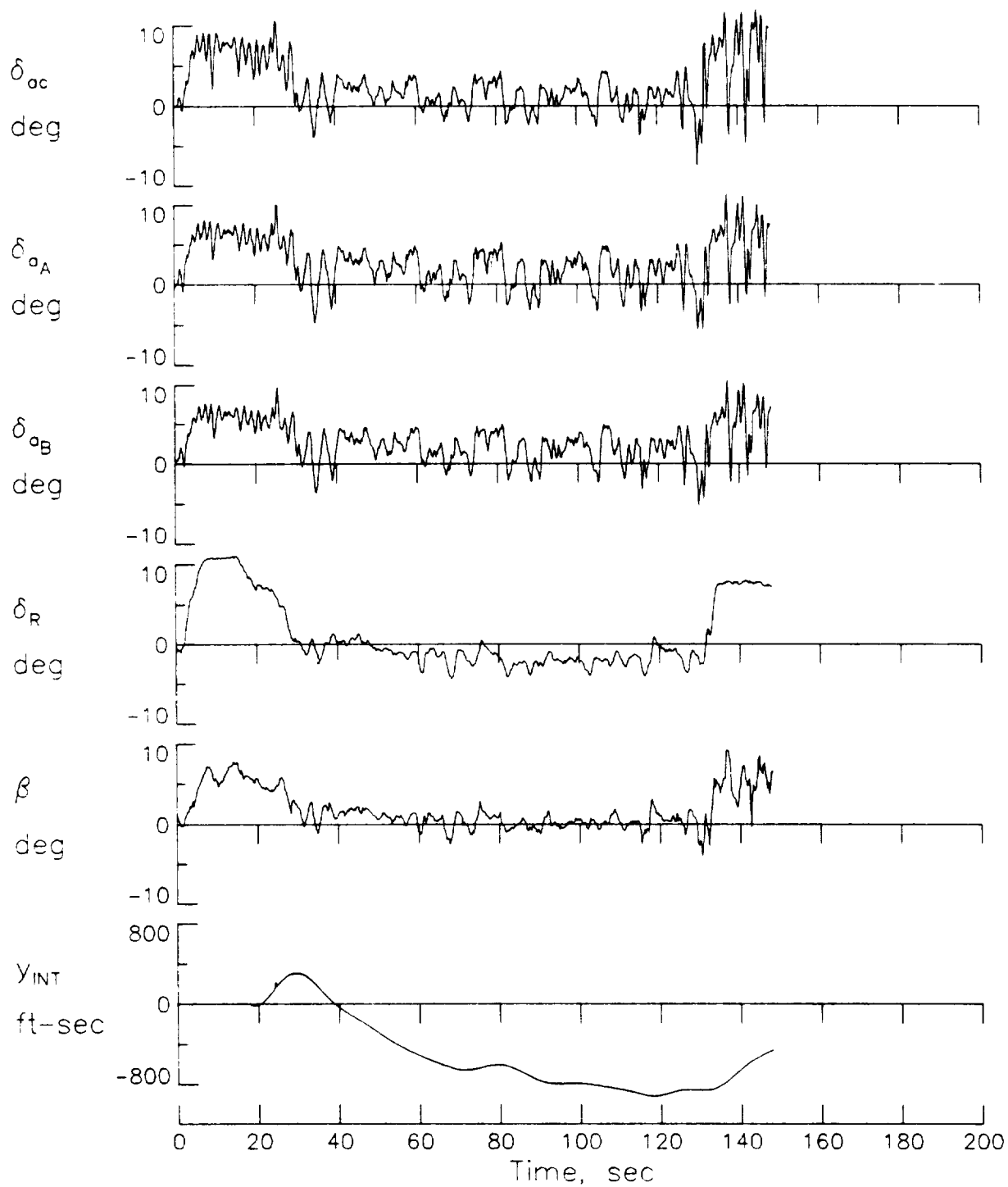


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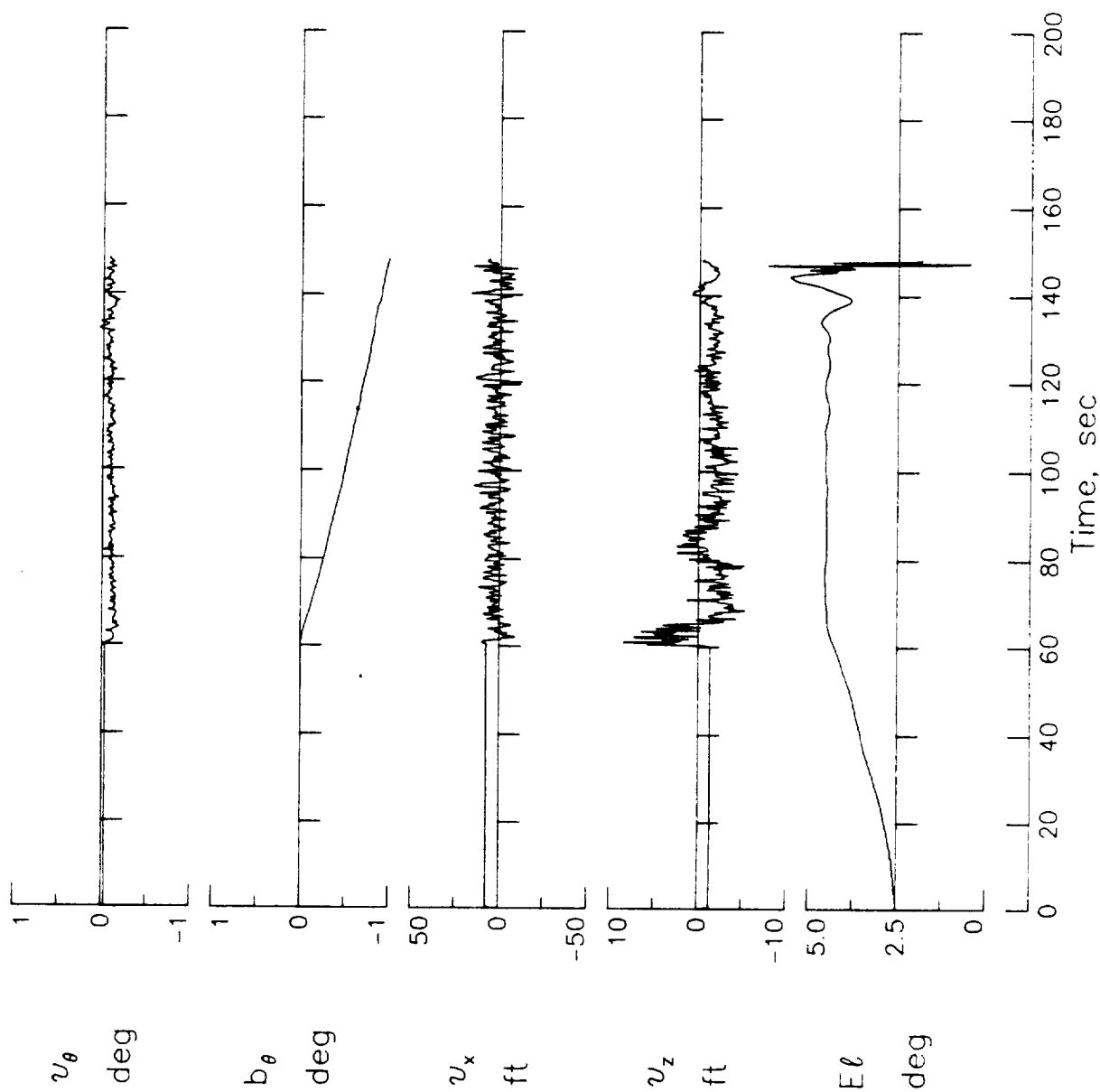


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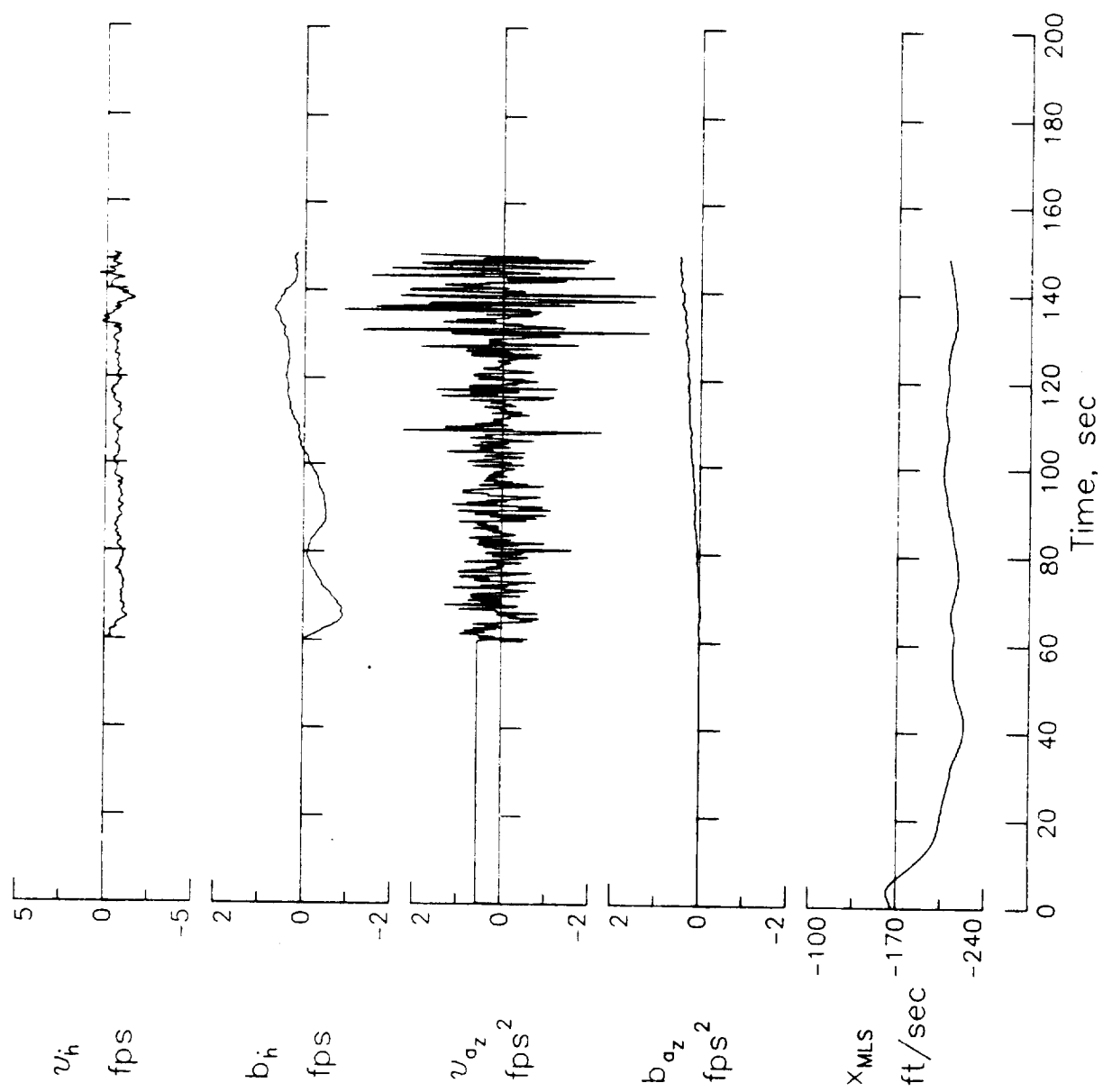


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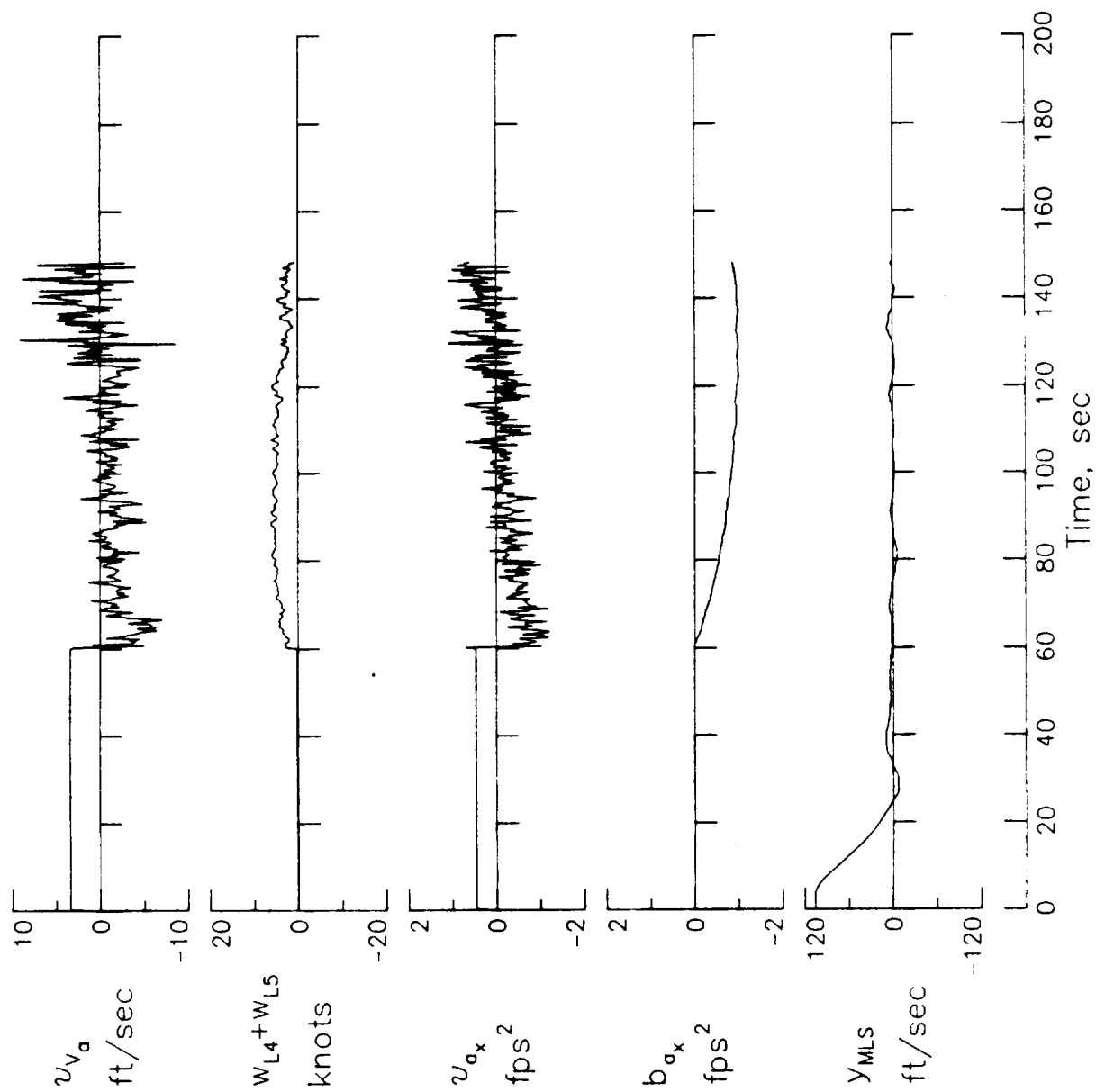


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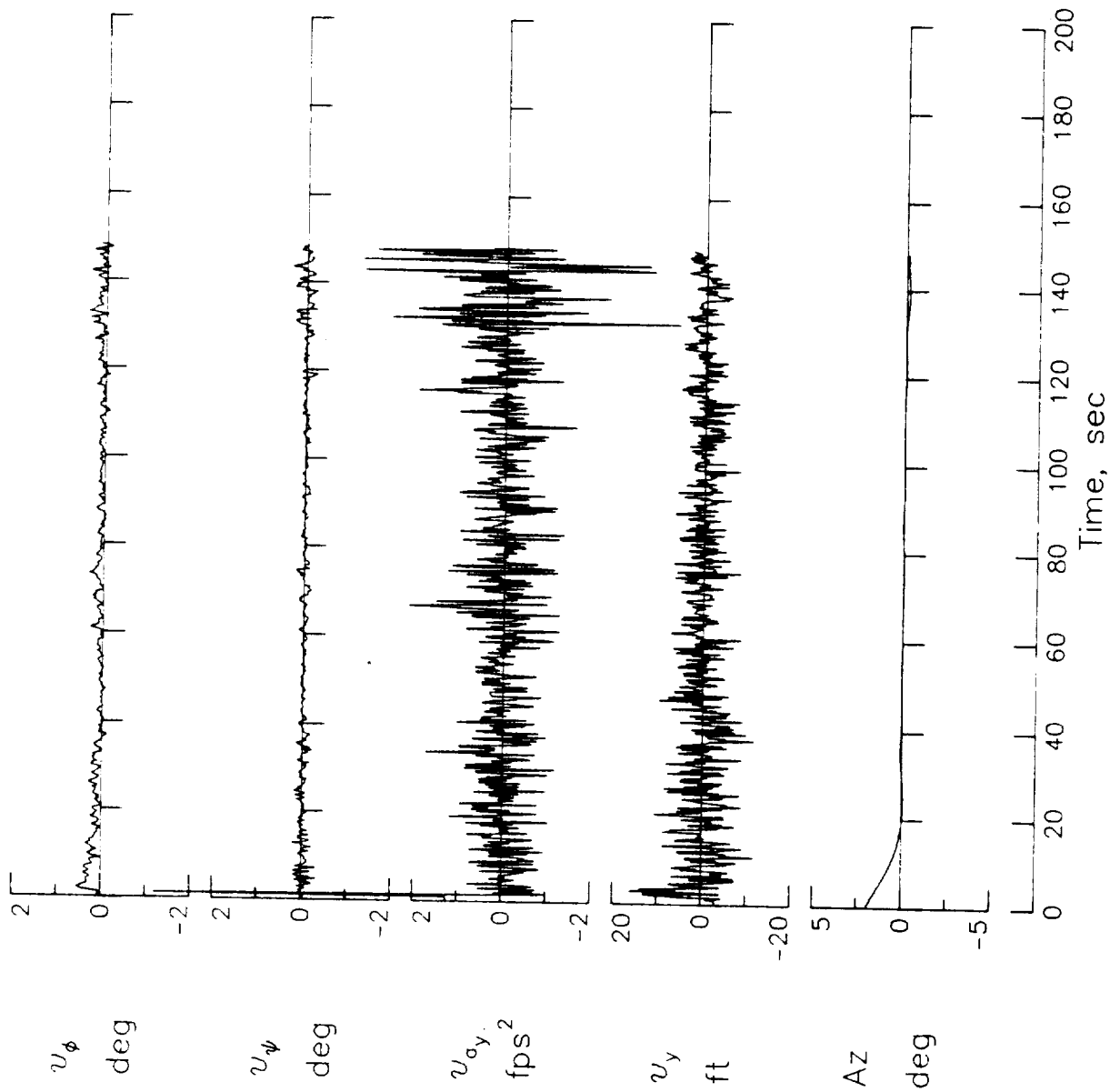


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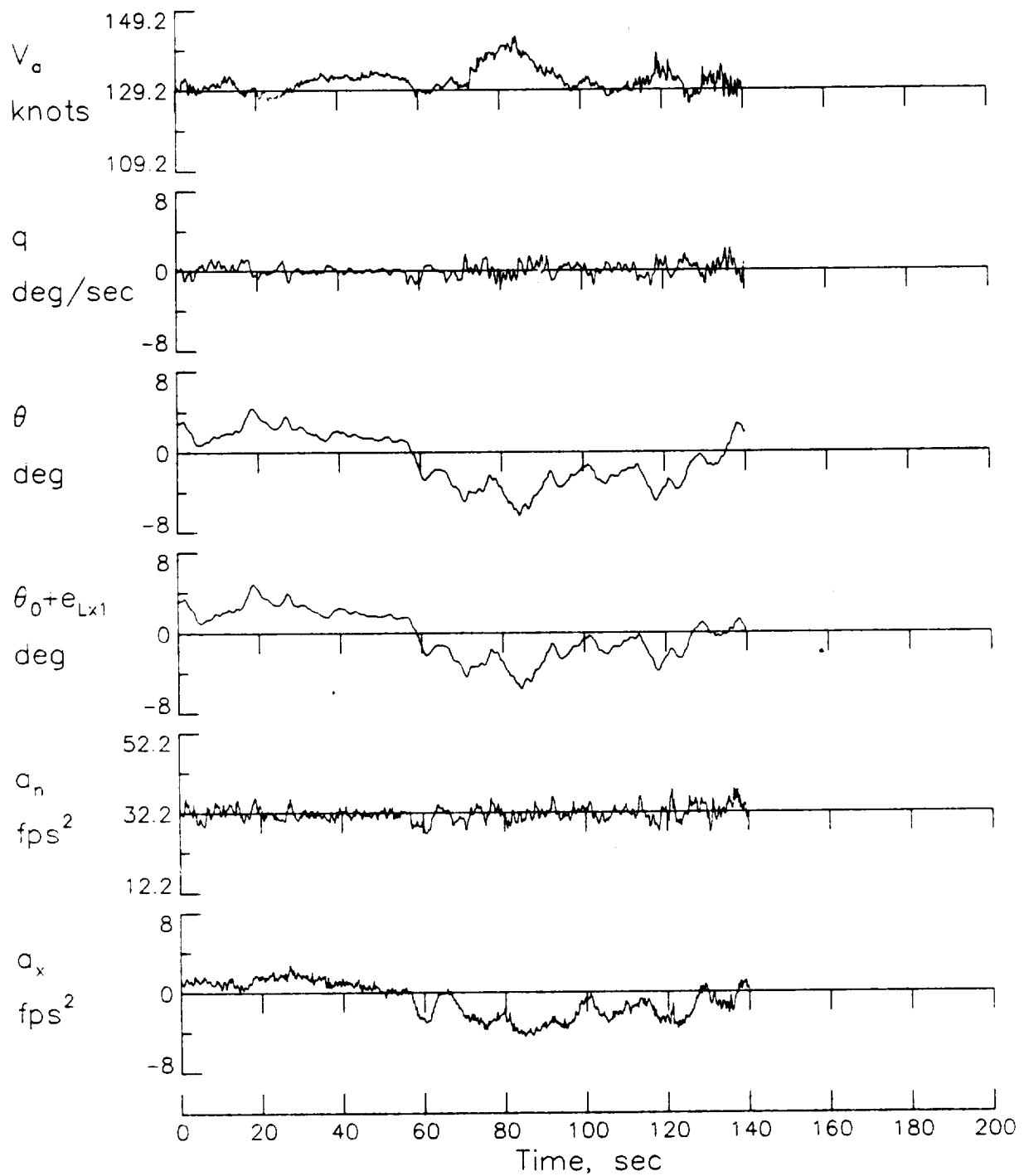


Figure 28. Flight Data for DIALS Flight Test
R364, Run 7

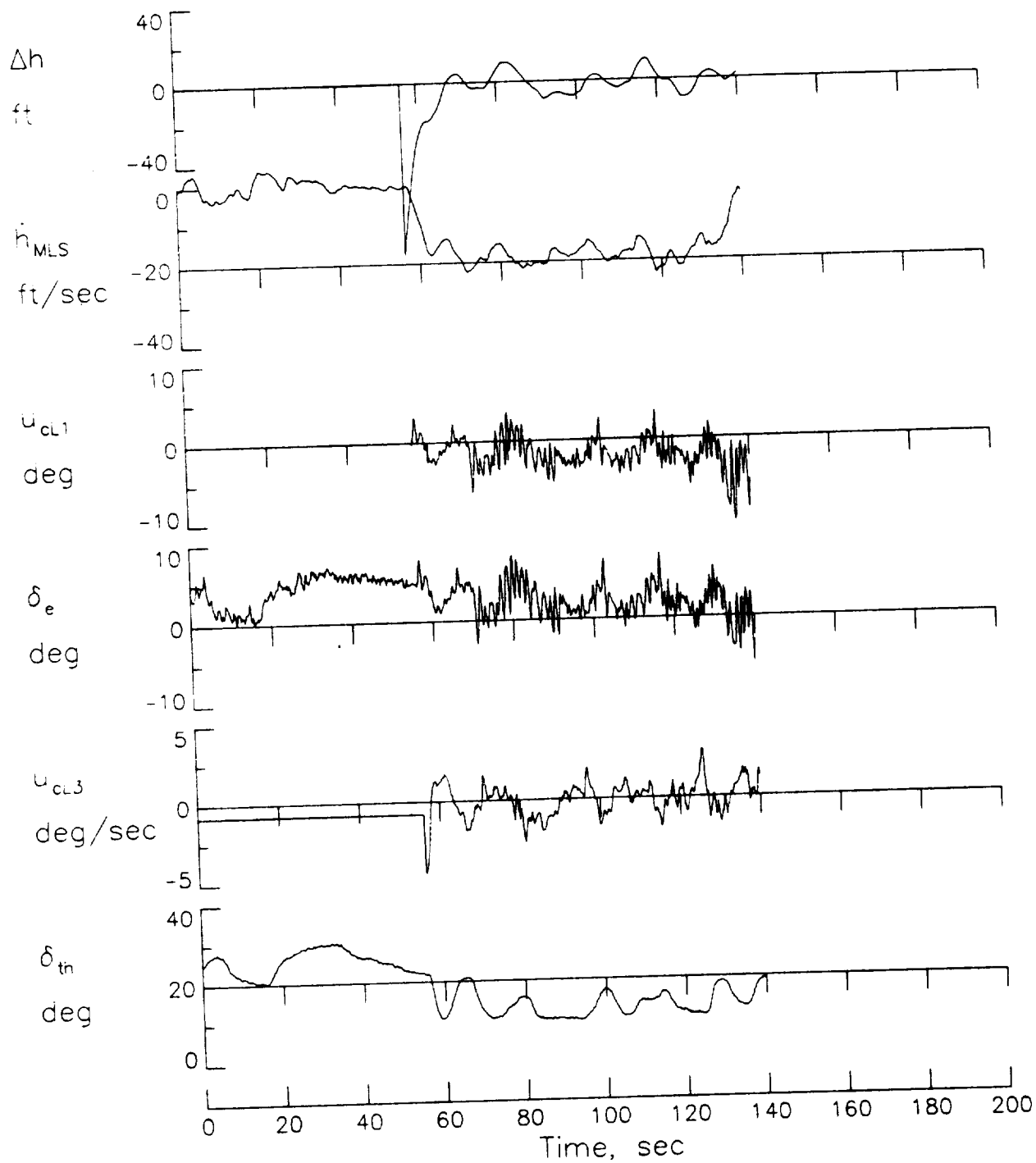


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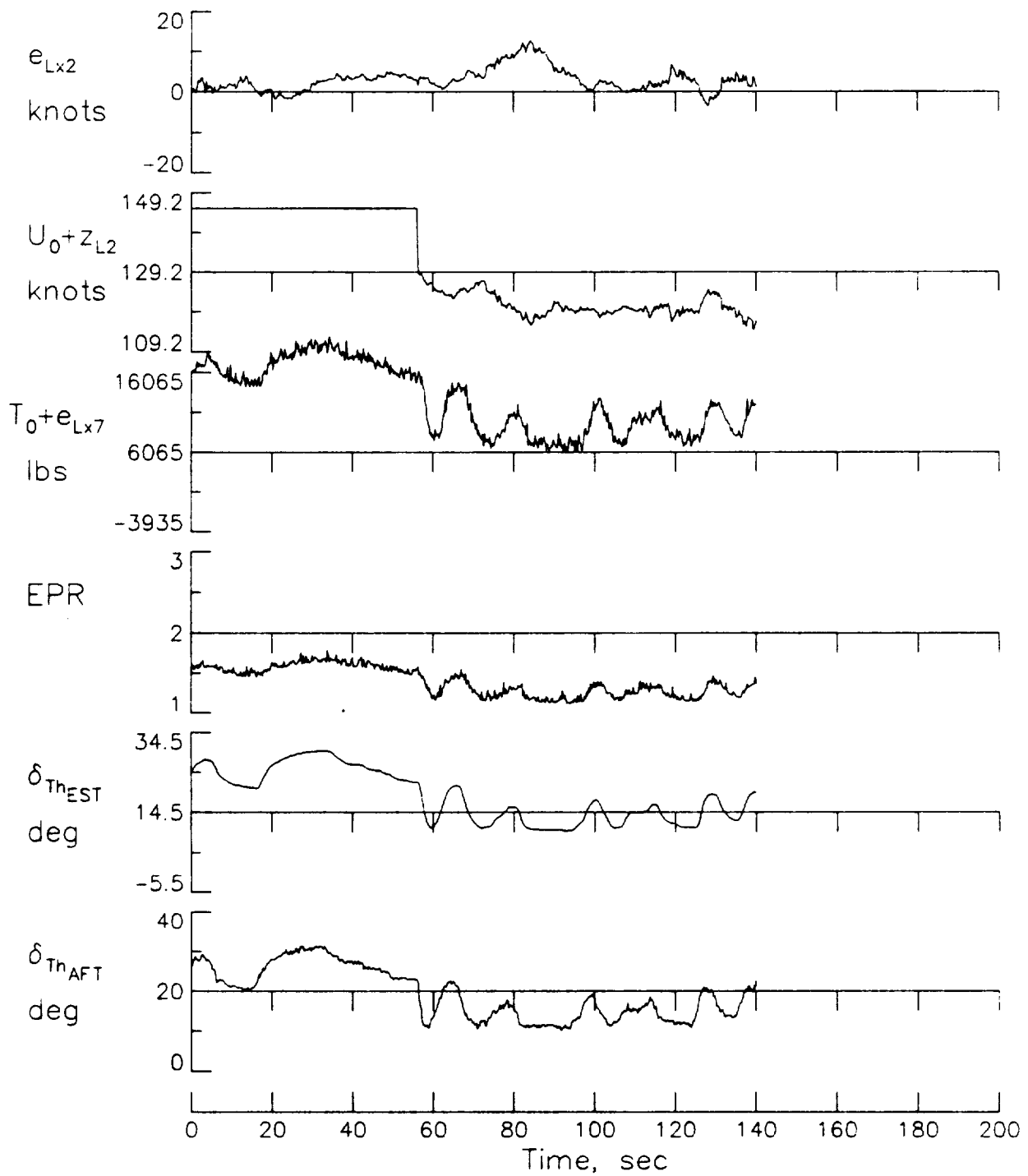


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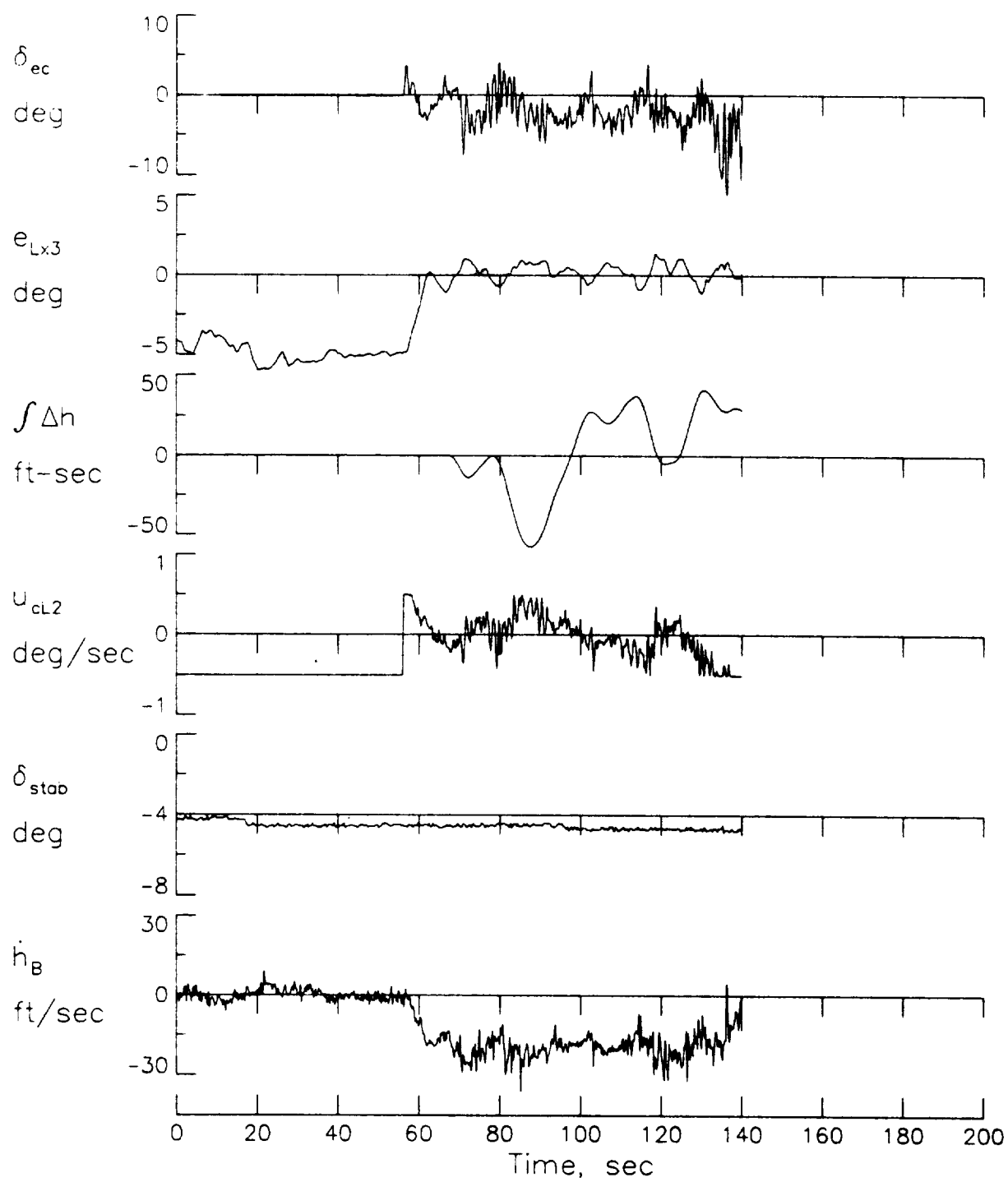


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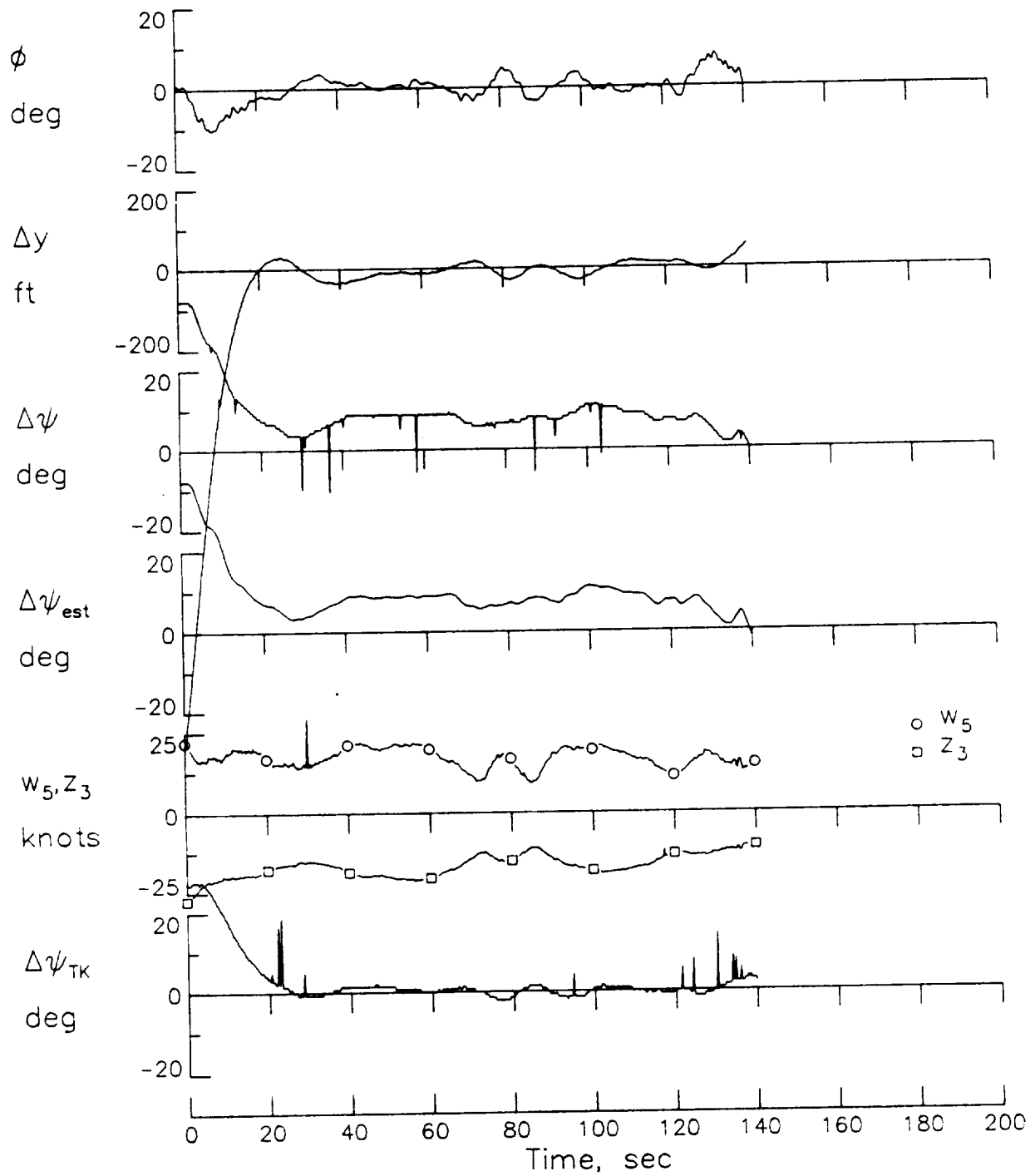


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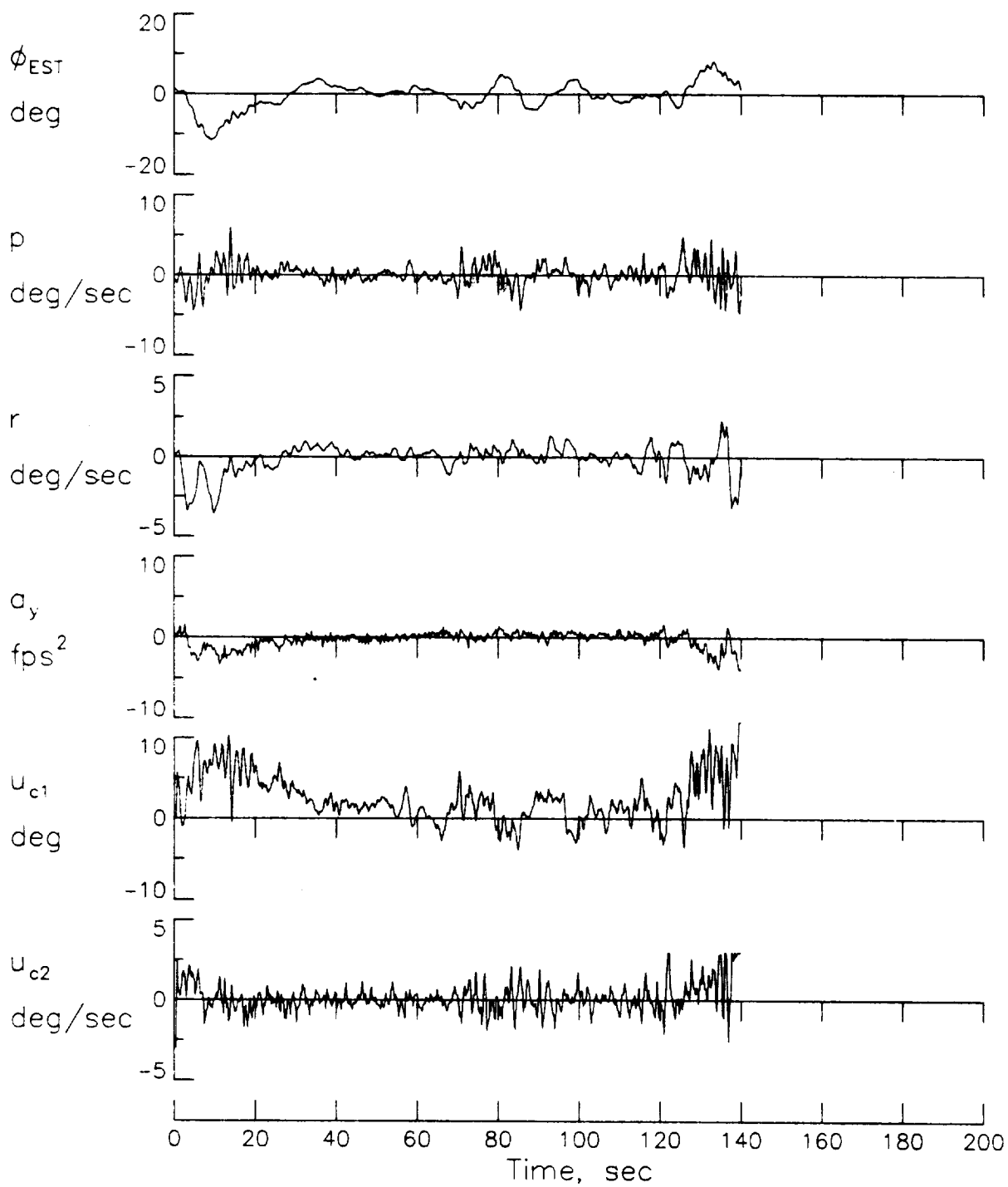


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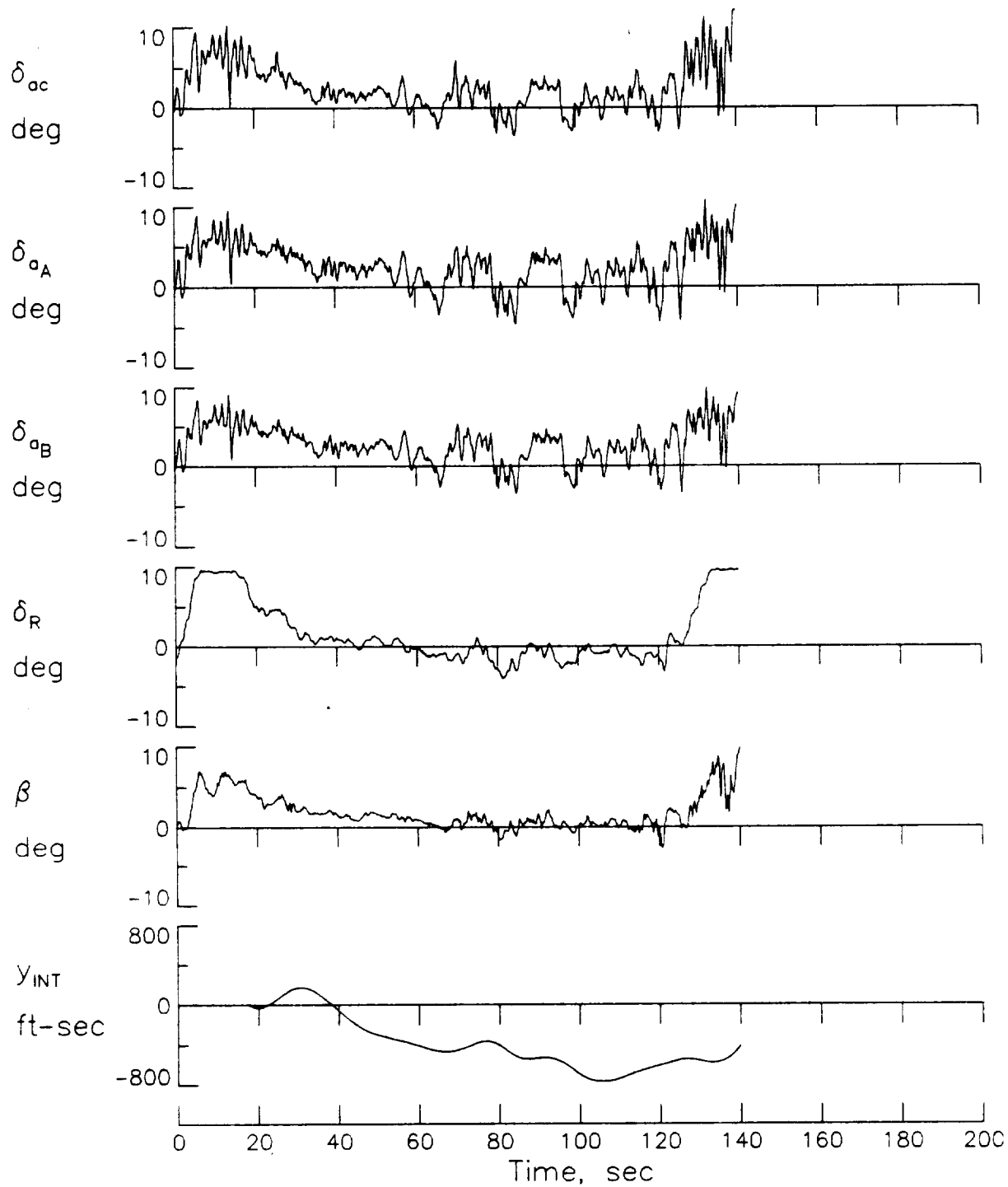


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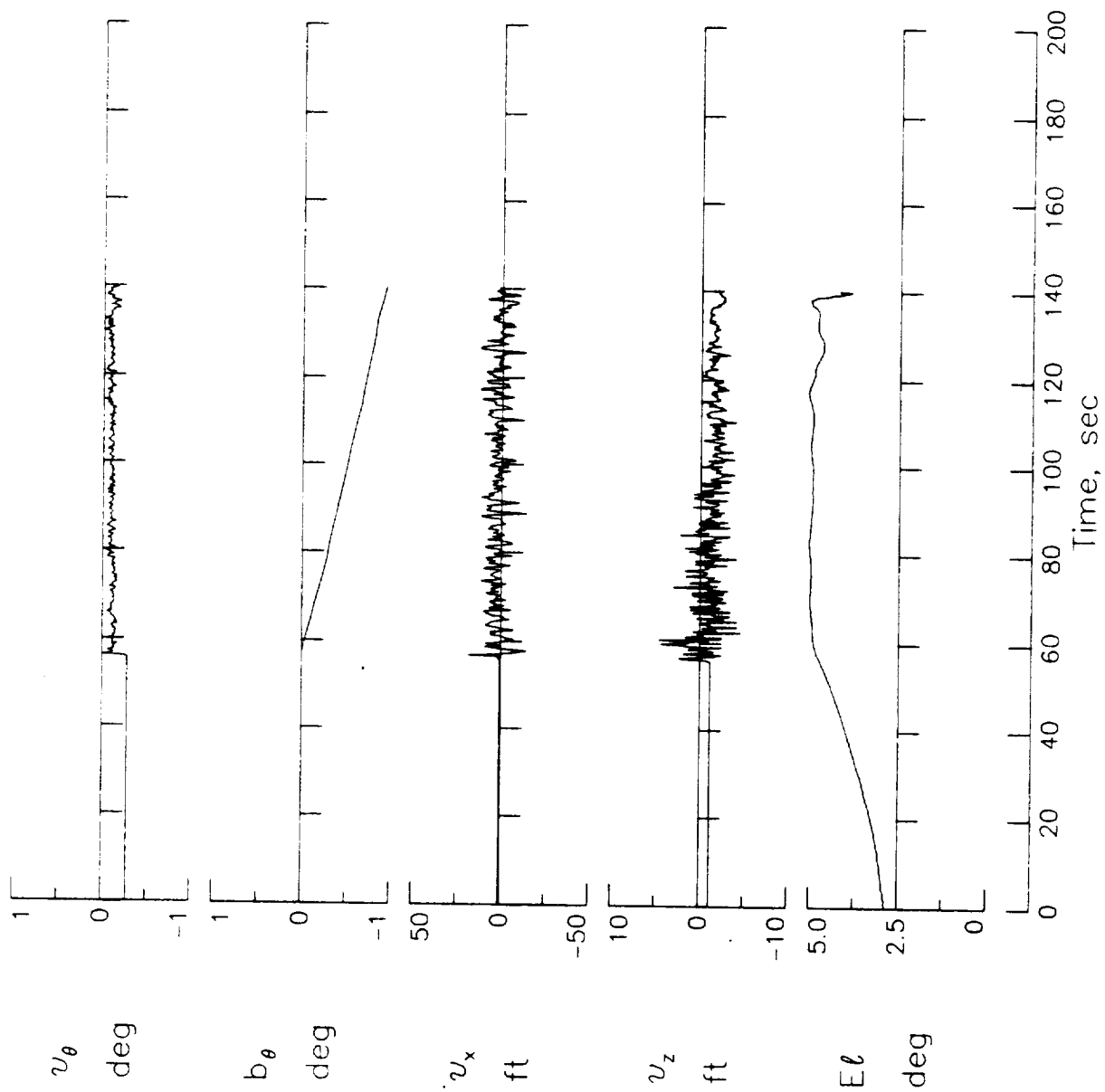


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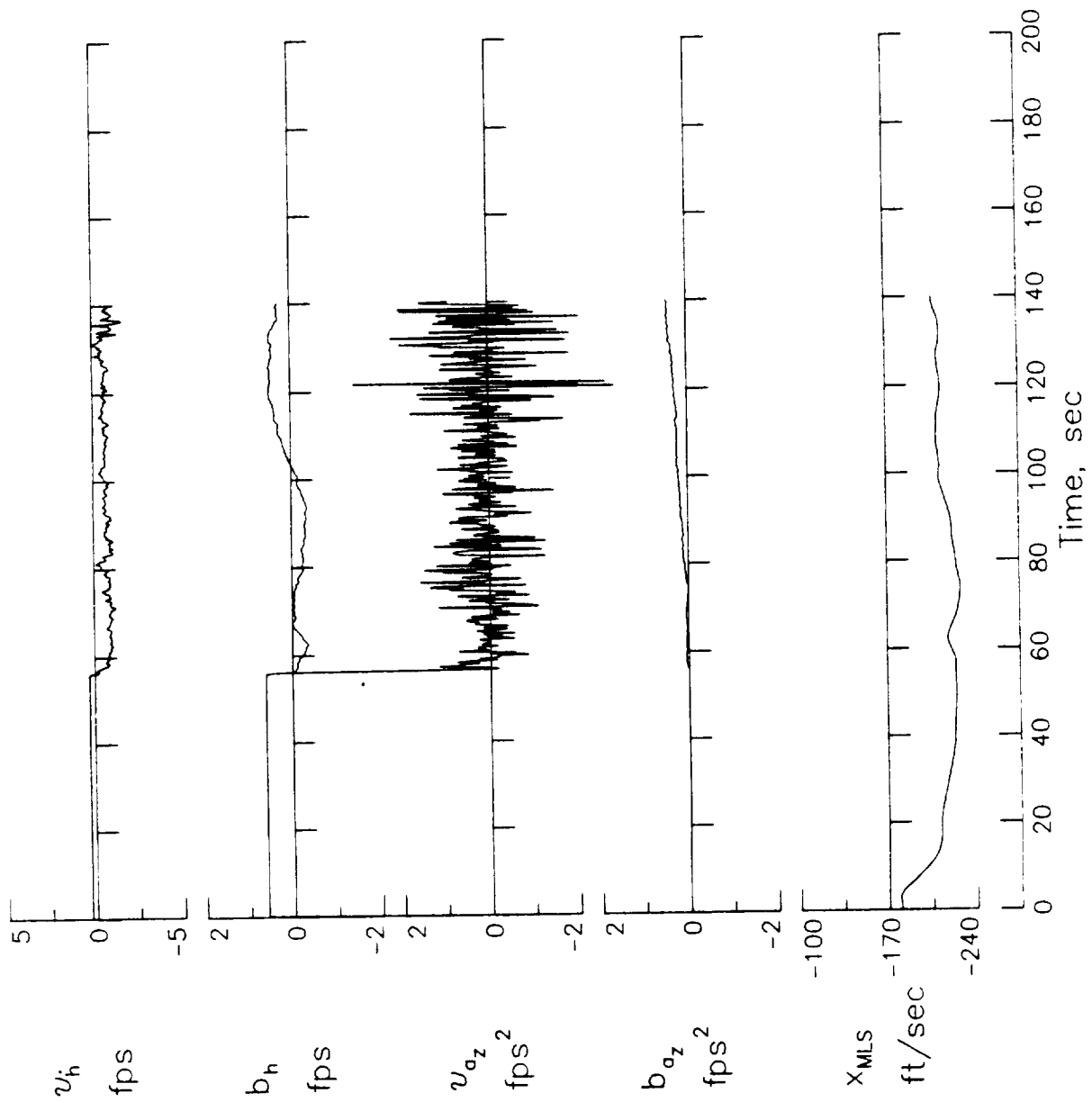


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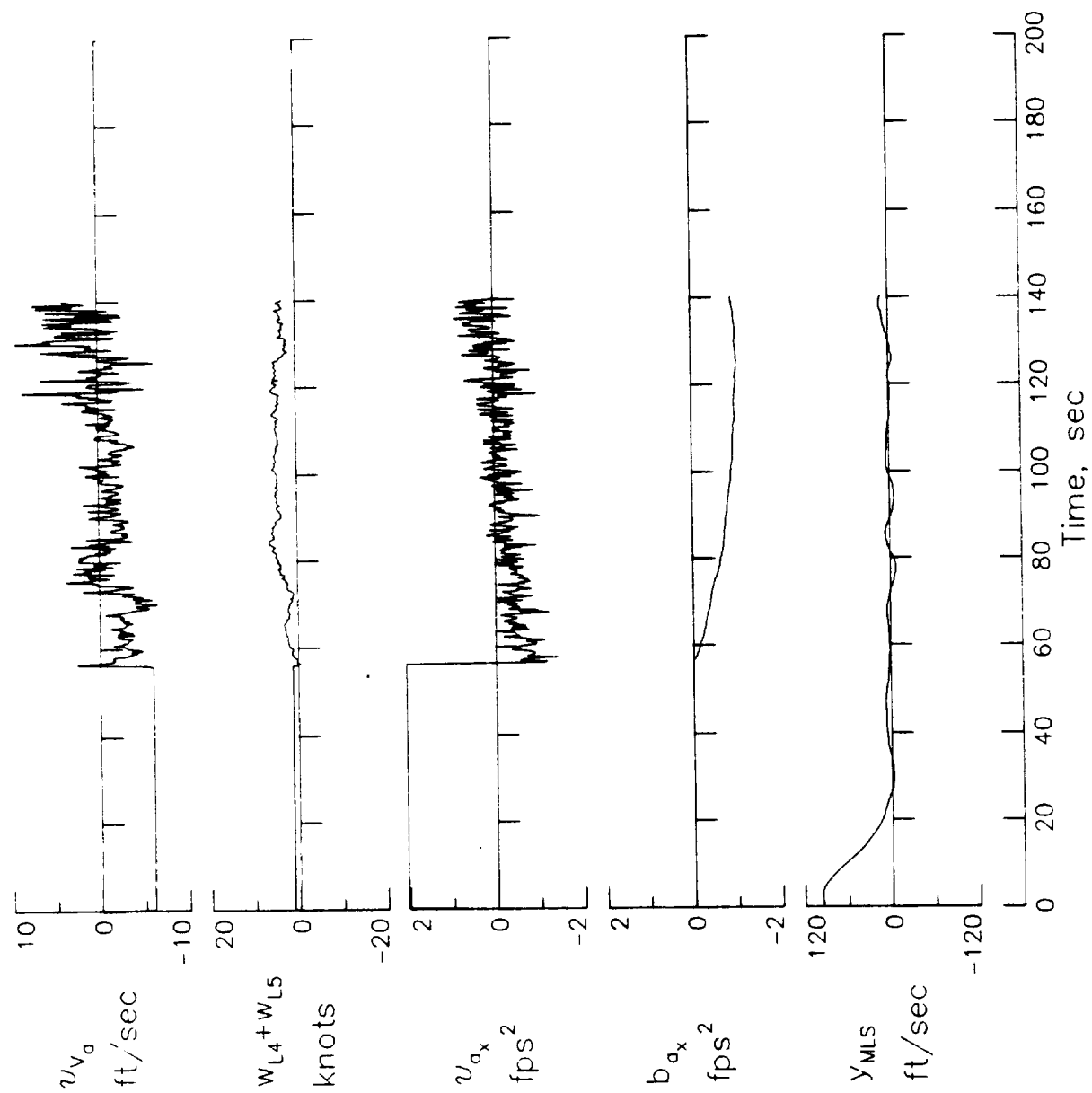


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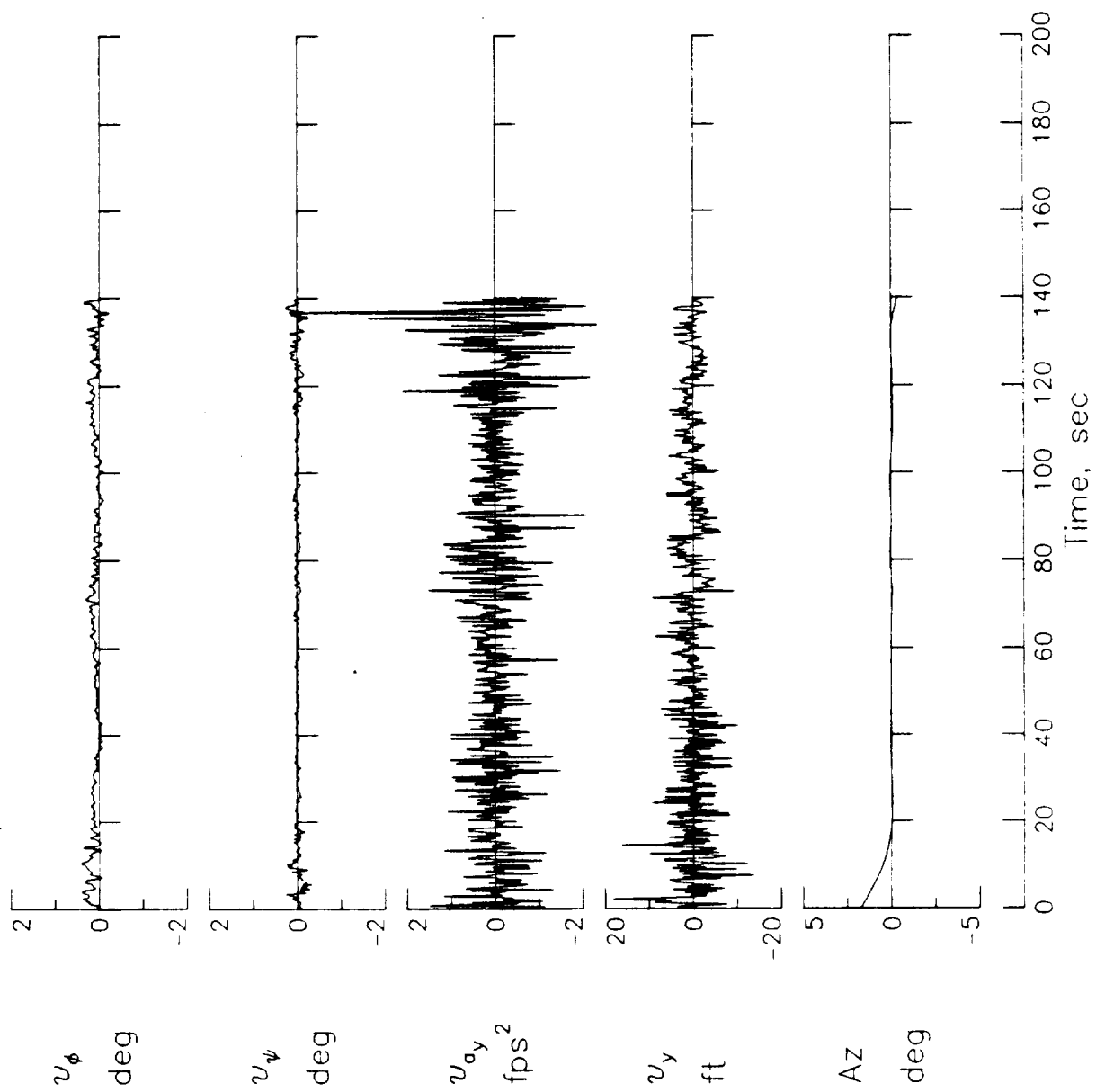


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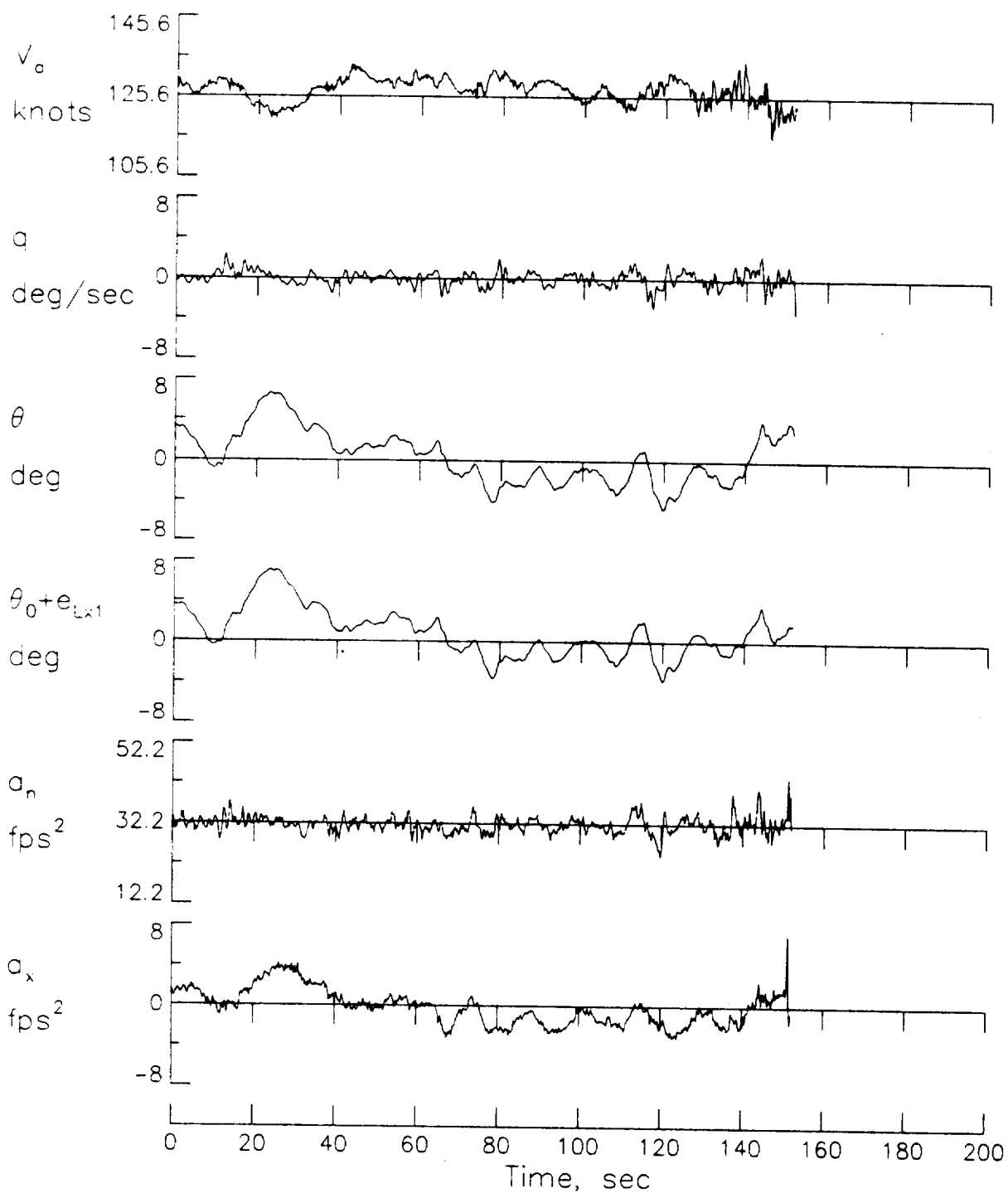


Figure 29. Flight Data for DIALS Flight Test R364, Run 6R1

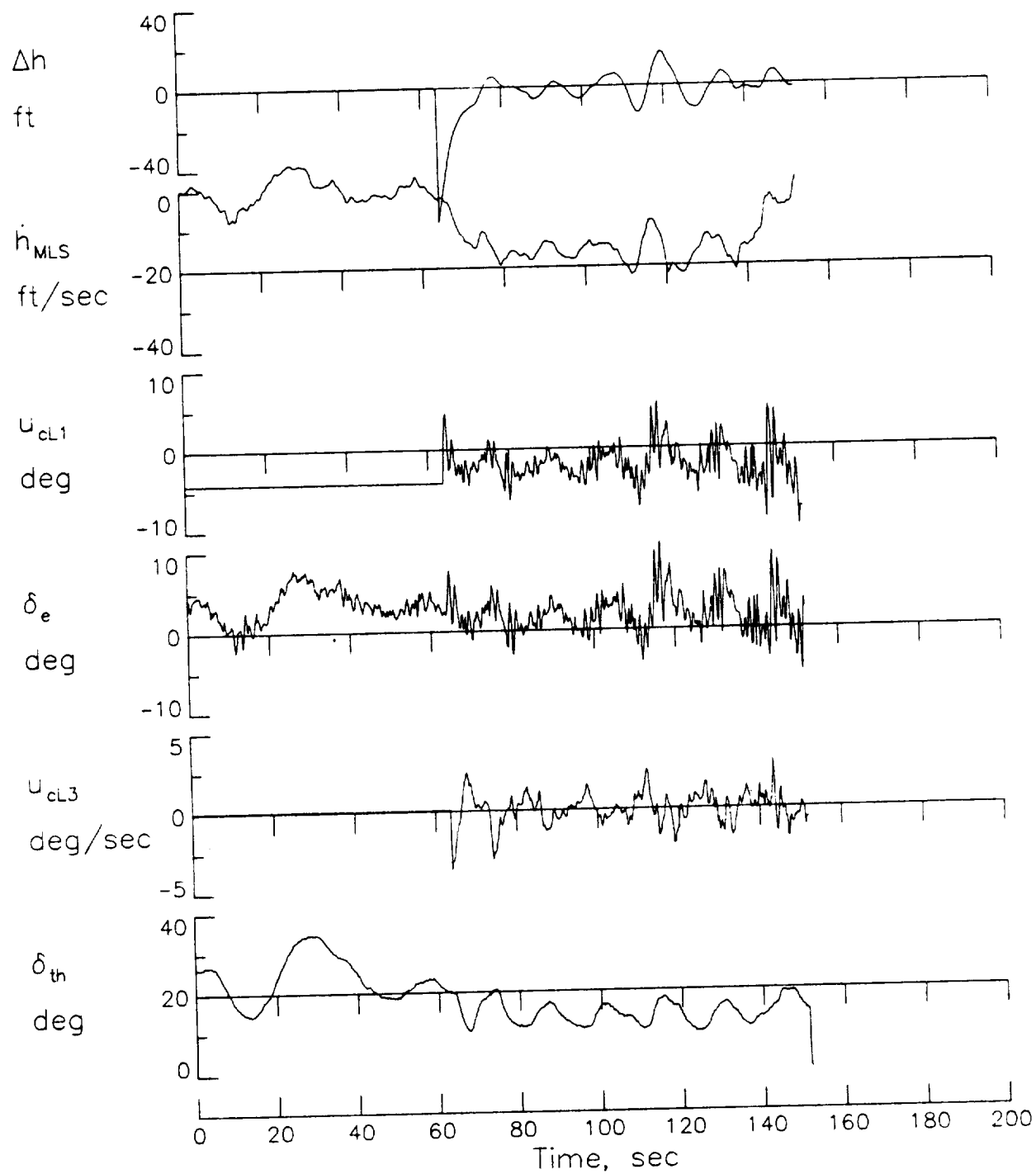


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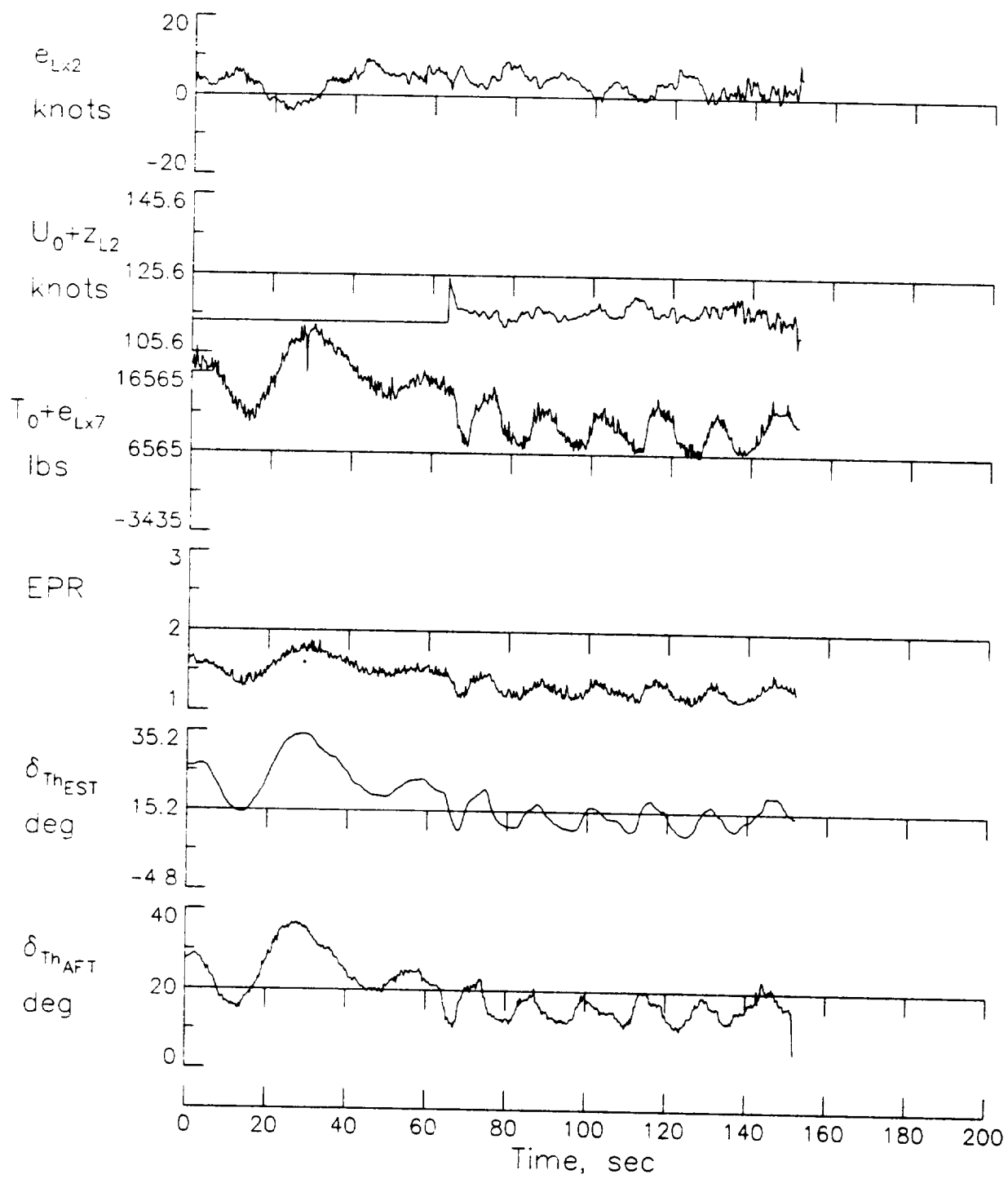


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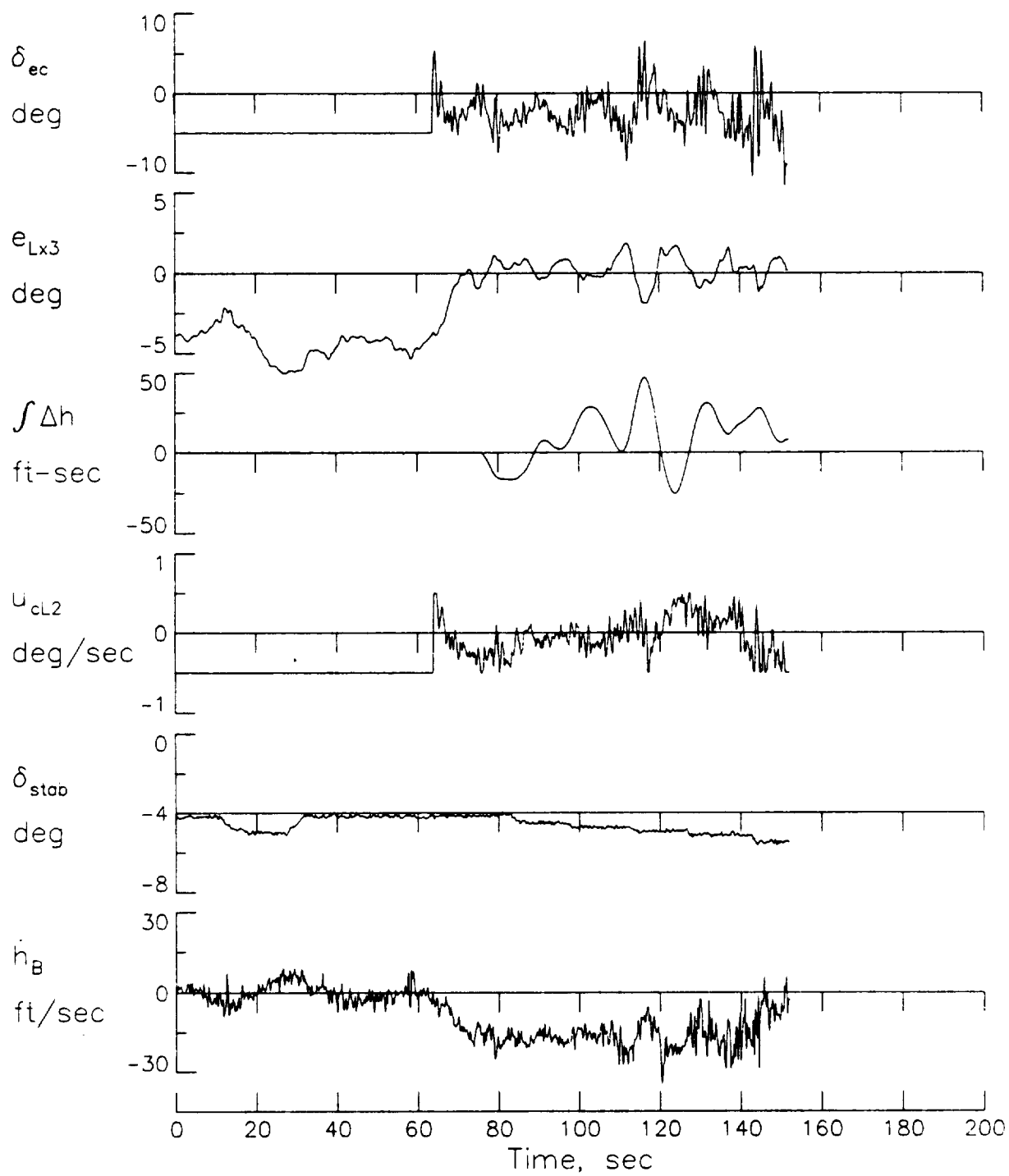


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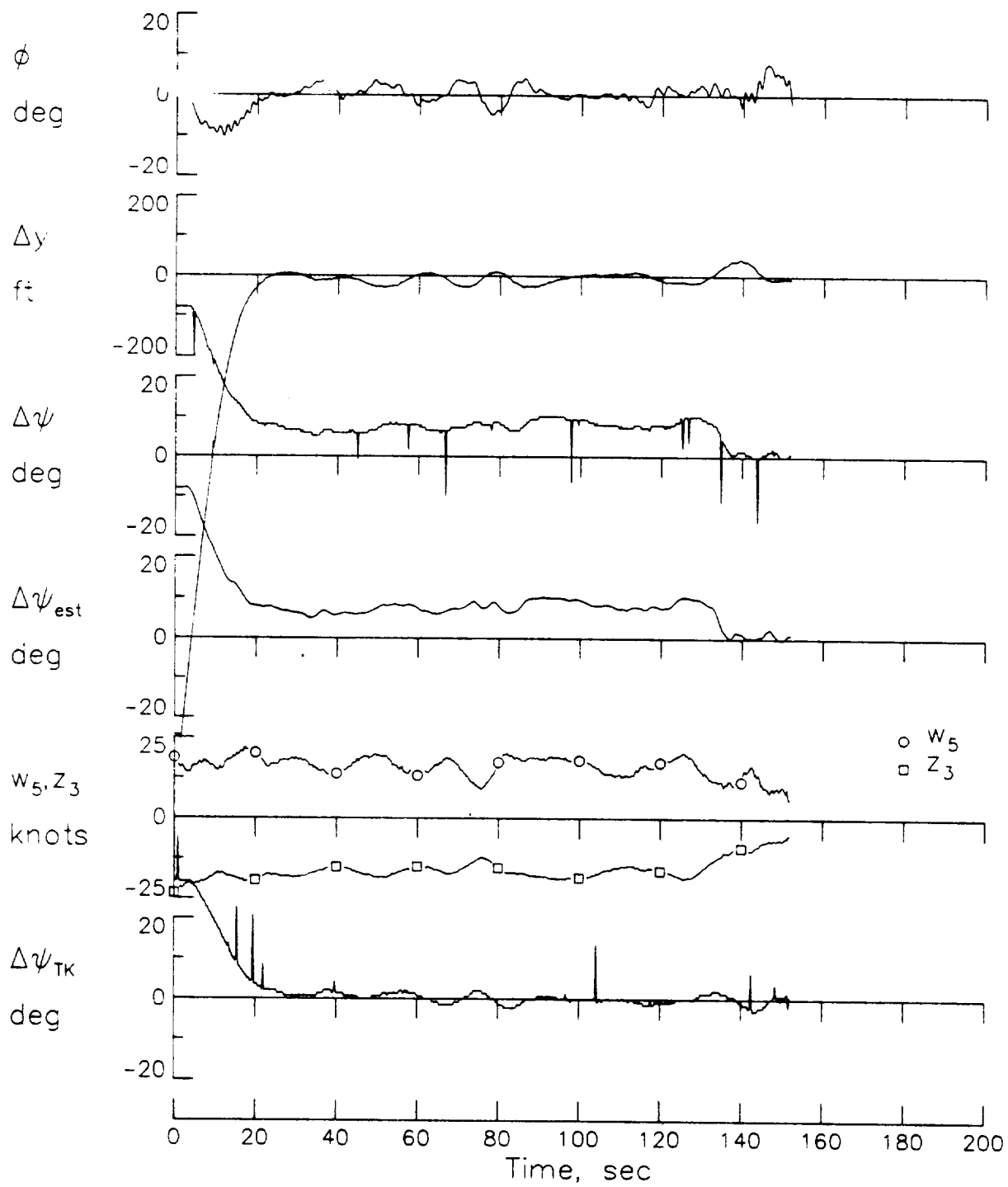


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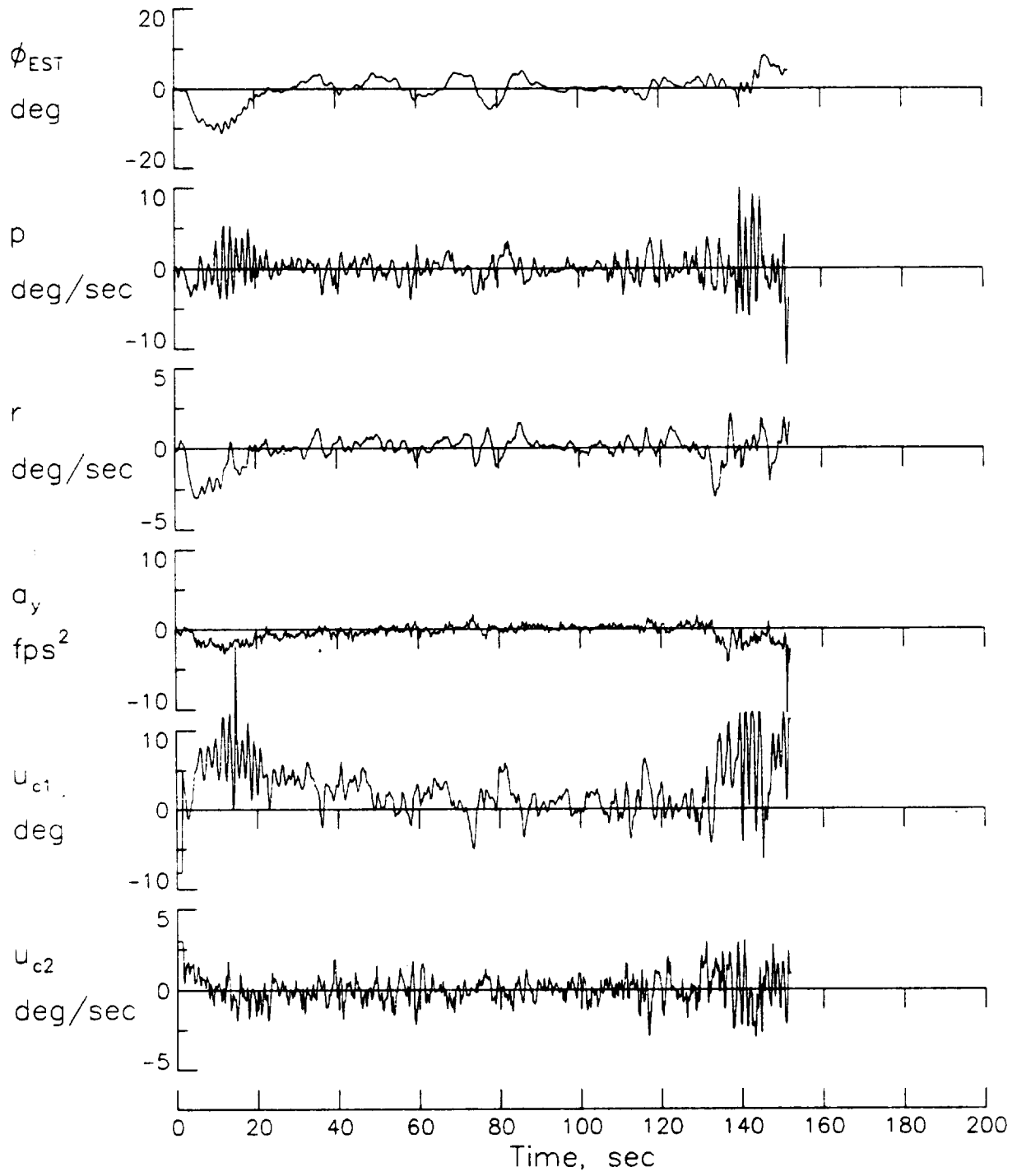


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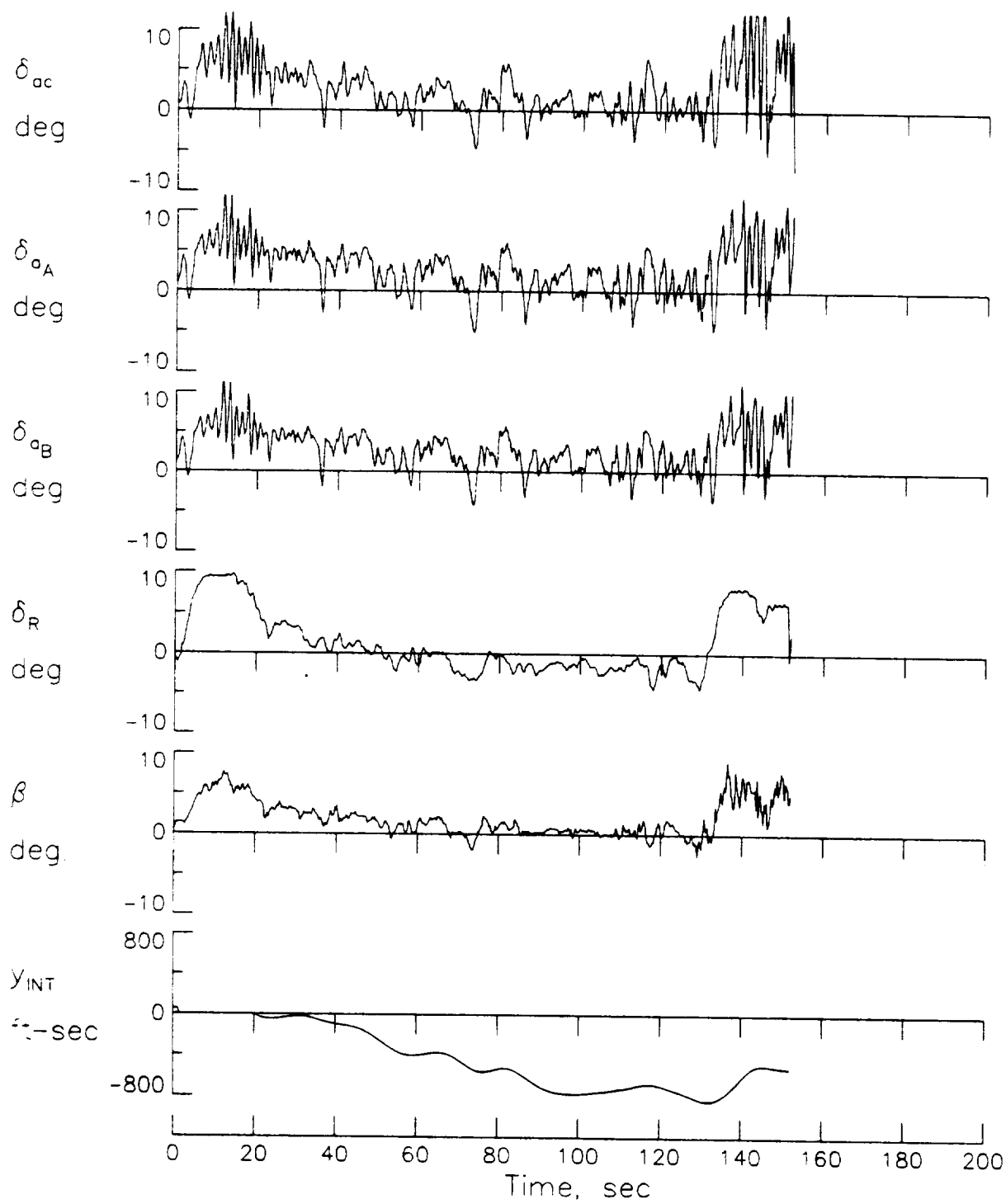


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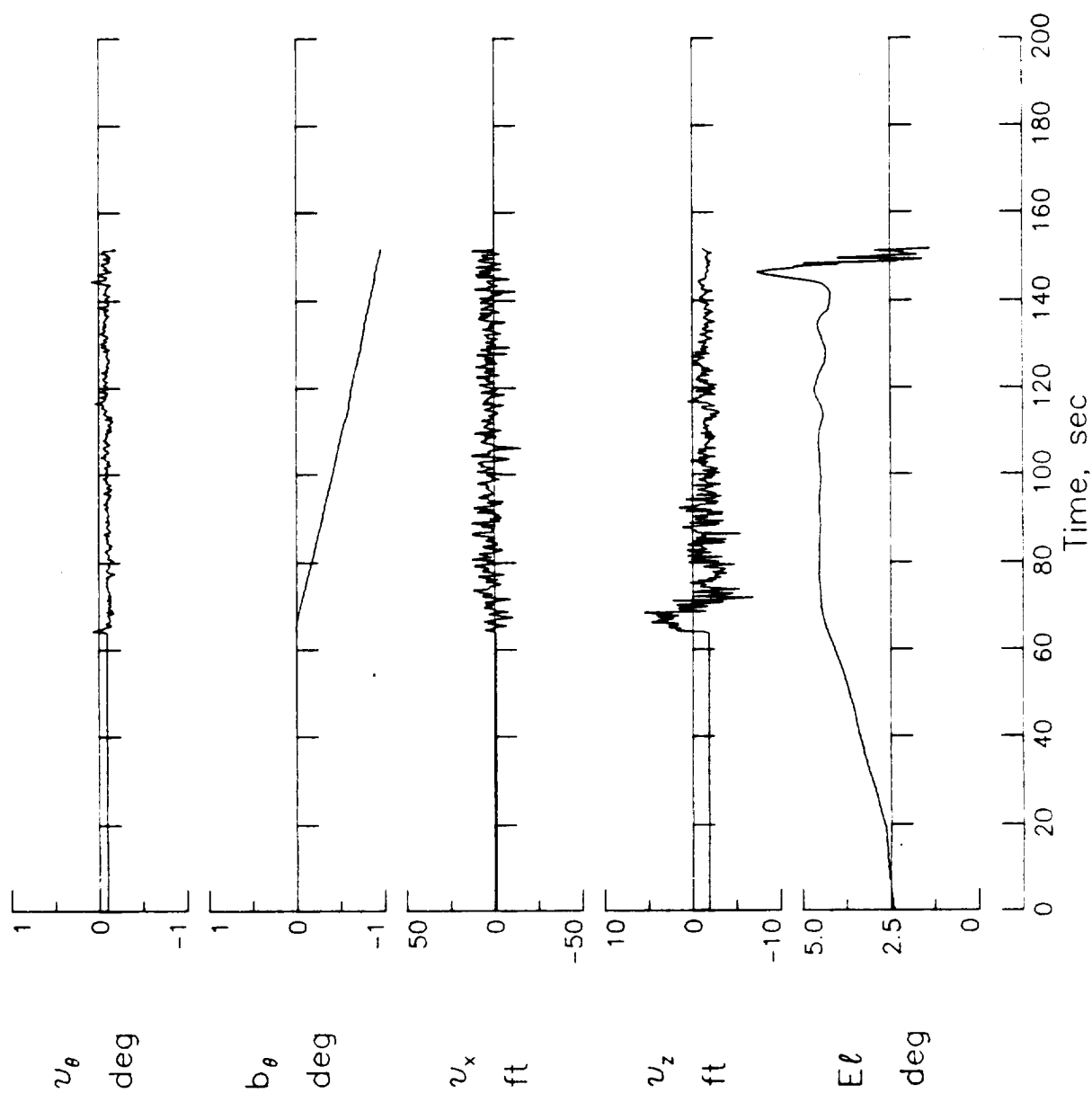


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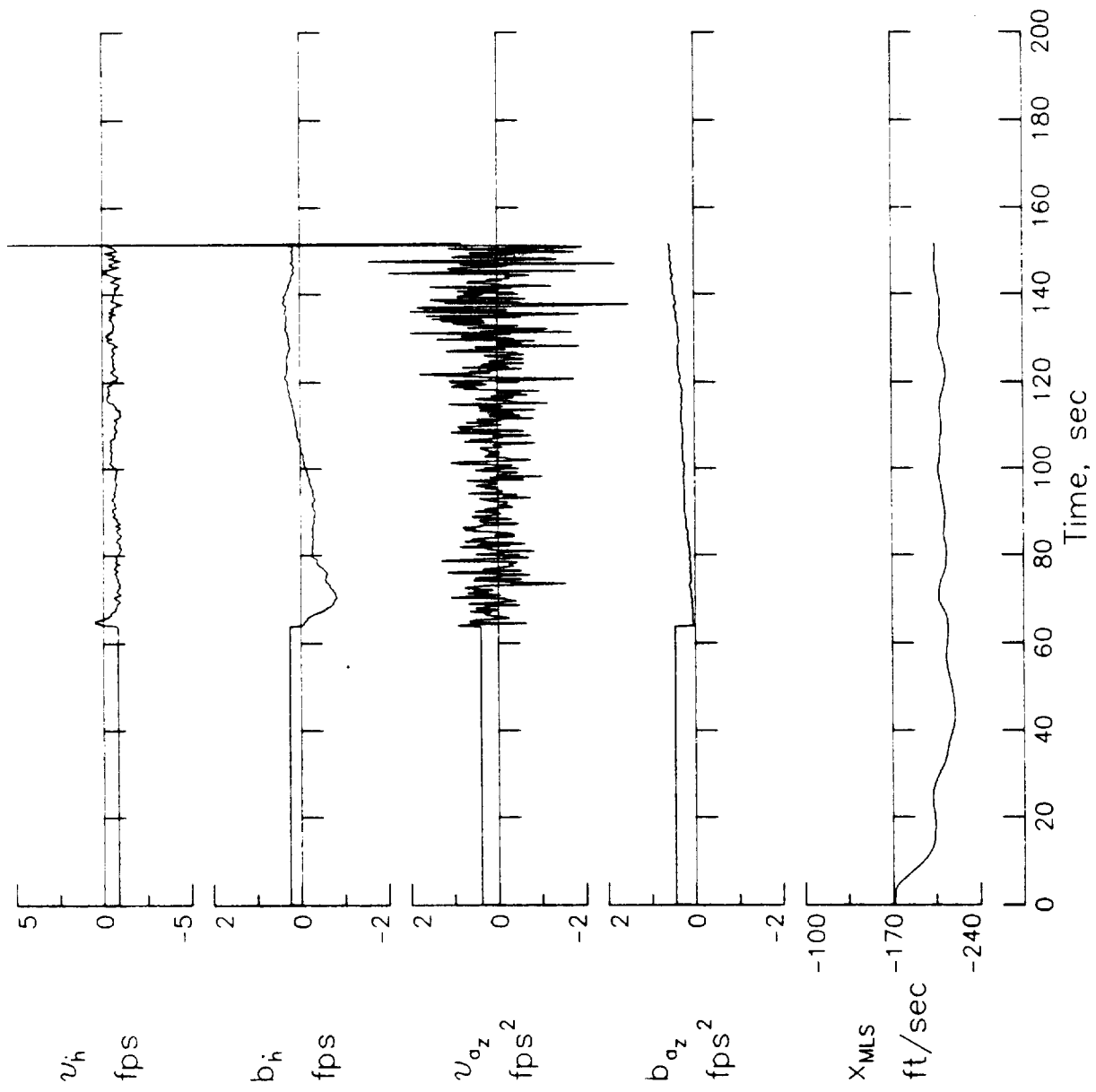


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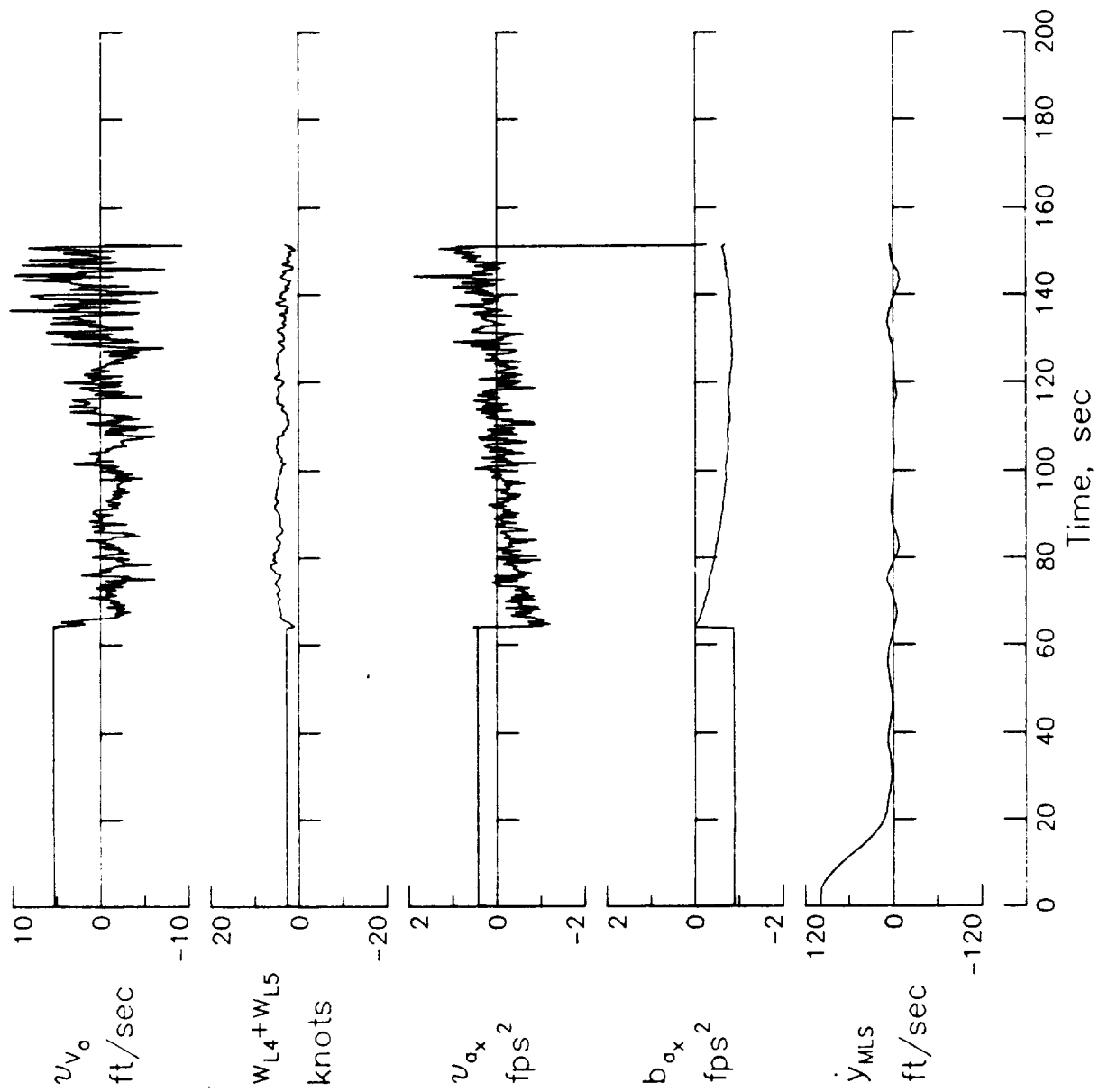


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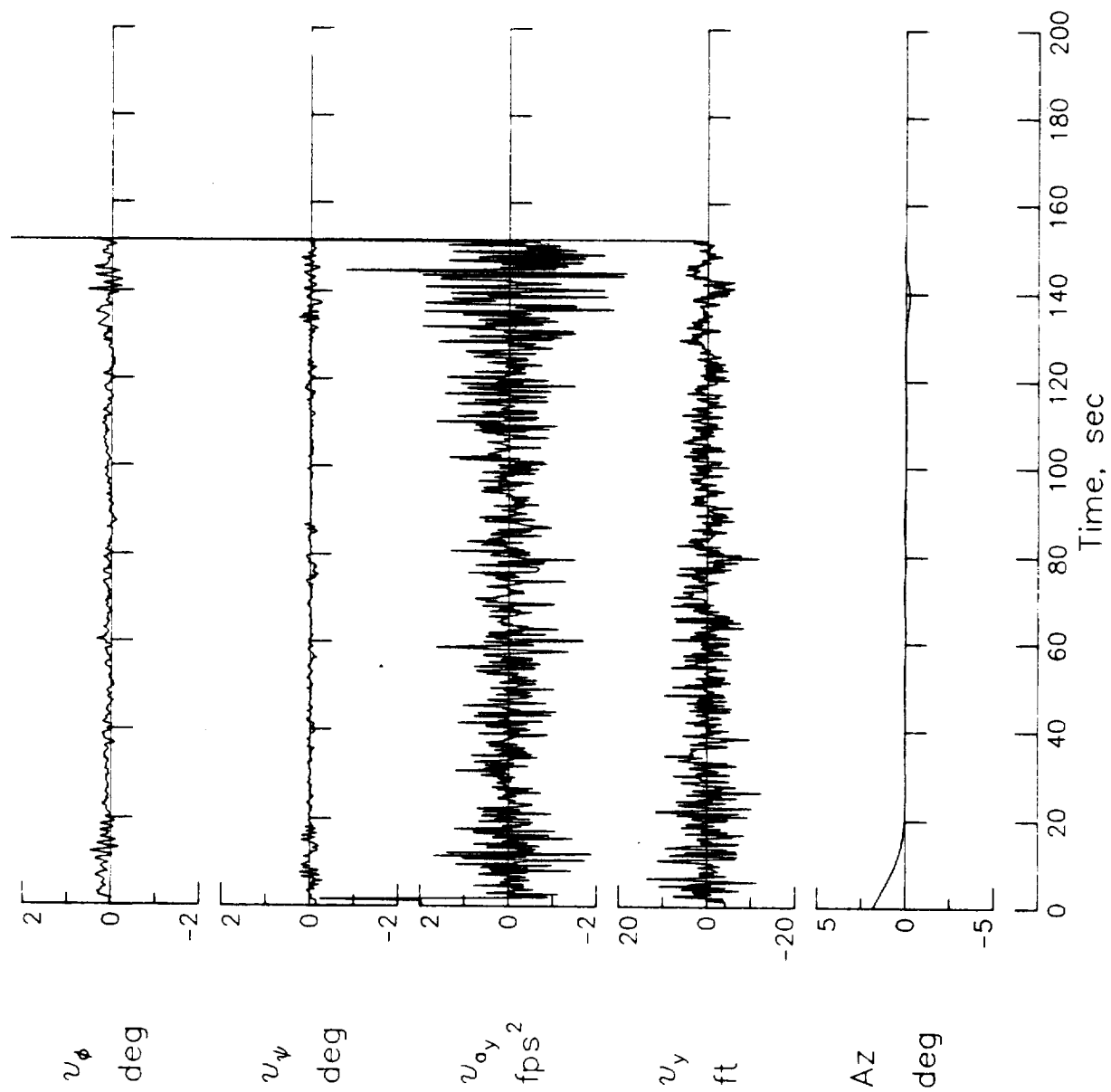


Figure 29. Concluded

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16. Abstract <i>Five flight tests of the Digital Automated Landing System (DIALS) were conducted on the Advanced Transport Operating System (ATOPS) Transportation Research Vehicle (TSRV)--a modified Boeing 737 Aircraft for advanced controls and displays research. These flight tests were conducted at NASA's Wallops Flight Center using the Microwave Landing System (MLS) installation on Runway 22. This report is primarily a collection of data plots of all performance variables recorded for the entire five flight tests. A description and source of the performance variables is included. Performance variables include inertial data, air data, automatic control commands, control servo positions, sensor data, DIALS guidance and control parameters, and Kalman filter data. This data illustrates low overshoot captures of the localizer for intercept angles of 20°, 30°, 40°, and 50° intercept angles, and low overshoot captures of the glideslope slope for 3°, 4.5°, and 5° glideslopes. Flare maneuvers were successfully performed from the various glideslope angles and good decrab maneuvers were performed in crosswinds of 6 knots. In 18-20 knot crosswind conditions rudder limiting occurred which caused lateral drifting although heading alignment was achieved.</i>					
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